

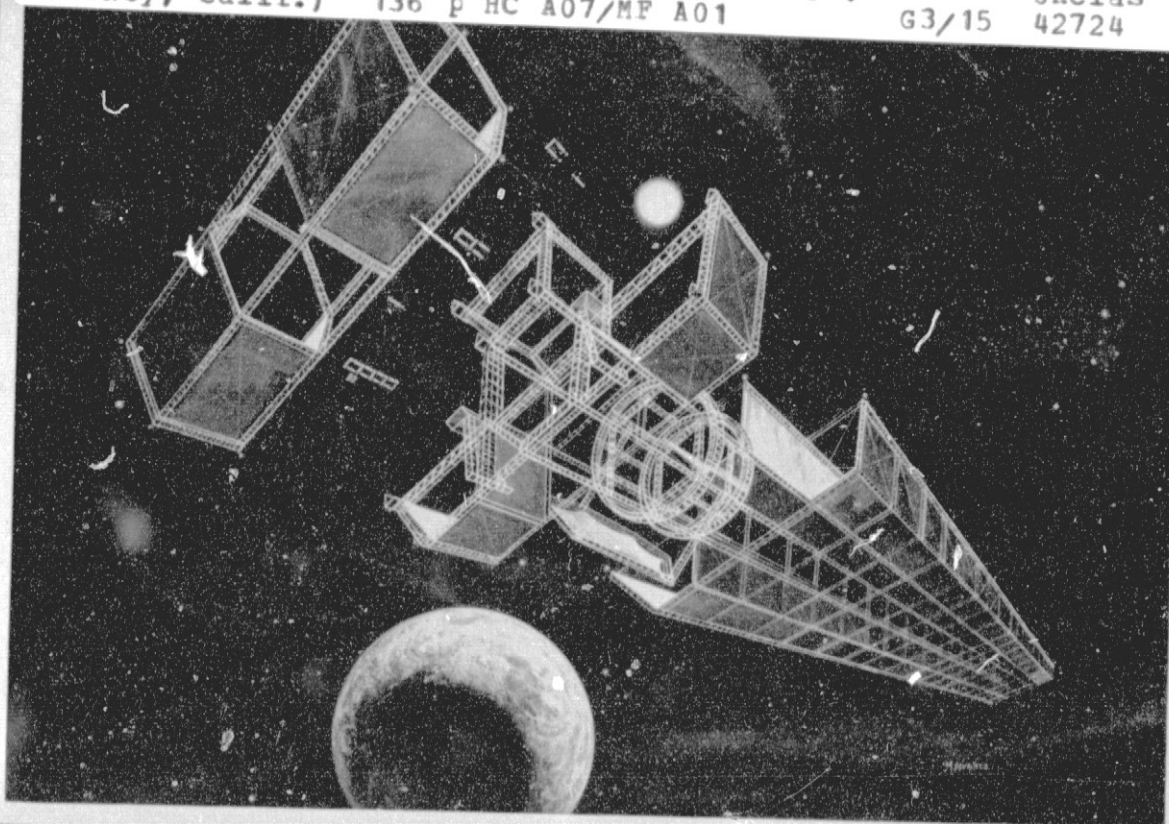
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Satellite Power Systems (SPS) Concept Definition Study

FINAL REPORT

VOLUME VI

SPS TECHNOLOGY REQUIREMENTS
AND VERIFICATION



Rockwell International

Space Division
12214 Lakewood Boulevard
Downey, California 90241



SD 78-AP-0023-6

Satellite Power Systems (SPS) Concept Definition Study

FINAL REPORT
VOLUME VI

SPS TECHNOLOGY REQUIREMENTS AND VERIFICATION

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FOREWORD

This document, *SPS Technology Requirements and Verification* is Volume VI of the SPS Concept Definition Study (Contract NAS8-32475), Exhibits A and B, and also incorporates results of NASA/MSFC in-house effort. This volume includes a *Supporting Research and Technology* summary. Other volumes of the final report that provide additional detail are listed below.

Volume

I	Executive Summary
II	SPS System Requirements
III	SPS Concept Evolution
IV	SPS Point Design Definition
V	Transportation and Operations Analysis
VII	SPS Program Plan and Economic Analysis



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1.0 SPS TECHNOLOGY REQUIREMENTS AND VERIFICATION

The objective of the verification study was first to determine the key issues associated with the SPS system concepts and their subsystem elements, and then to develop a plan that defined the most desirable steps leading toward resolution of these key issues at the lowest possible cost.

The planning sequence, as shown in Figure 1.0-1, involved several steps. First, the literature was reviewed to identify the areas of concern (potential key issues). Second, a screening process was established to determine which

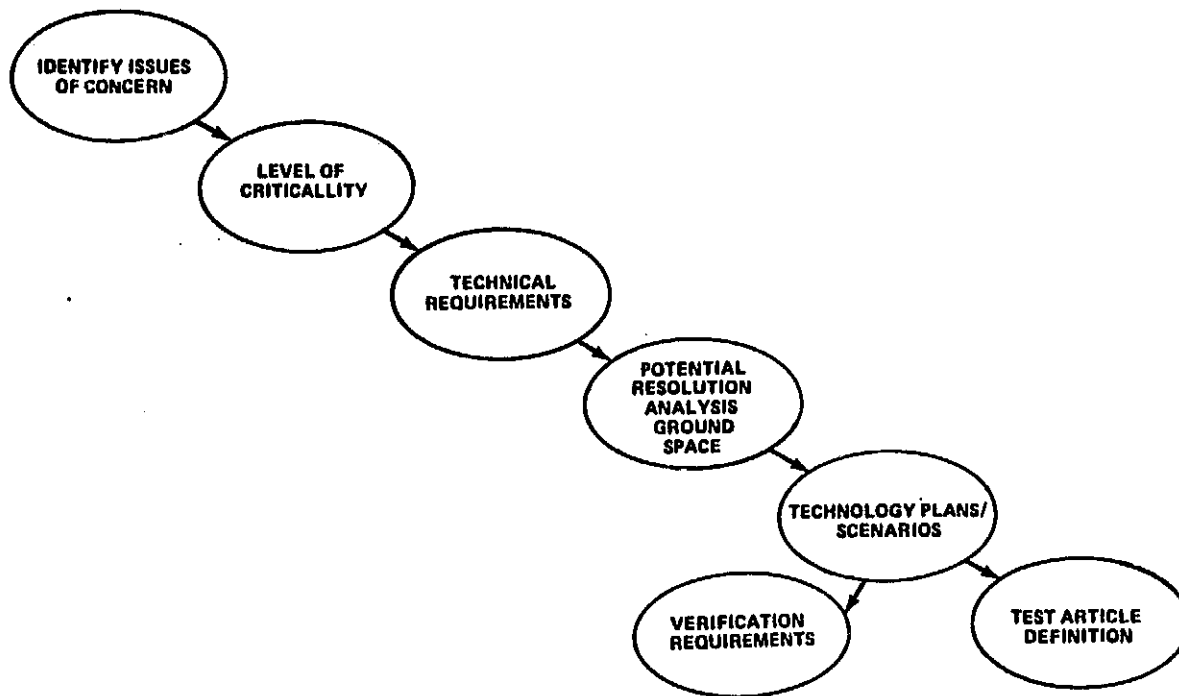


Figure 1.0-1. SPS Verification Activity

of these areas of concern were most critical to the success of the SPS program. The identified areas of concern were then categorized into three levels of criticality. Third, a brief description of what makes each of these issues significant was documented. Fourth, a potential method of resolving the issues was developed. This included resolution of issues by analytical techniques, ground verification, and space verification. Fifth, the potential methods of resolution were integrated into a consistent technology plan and verification program scenario. Sixth, the definition of the test articles as described in the technology plans and scenarios was initiated. In some cases, where the SPS program would need supporting assistance from other programs such as extended orbiter mission, large space structure assembly support facilities,



etc., the requirements of the SPS verification program would be defined rather than defining the test article. Where the test article was unique to the SPS program, then, the article would be defined.

It should be noted that this process is dynamic in nature. As the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), and their respective contractors penetrate the SPS program there will be some changes in the verification planning activity. The importance of an issue might diminish or increase, or a technique or procedure might be defined that would be more economical than one previously identified. Nevertheless, it is felt that the basic approach which is identified herein is a valuable technique that can and should be used to build a solid foundation for the SPS verification program.

1.1 IDENTIFICATION OF AREAS OF CONCERN

A review of the DOE and NASA in-house and contracted studies was conducted to extract the identified areas of concern. These previous and on-going studies had identified several issues covering the spectrum of SPS activities. These issues were consolidated (Table 1.1-1) into a composite list which was used as a data base from which to derive the most critical issues.

1.2 LEVEL OF CRITICALITY

The previously described list of identified areas of concern was then used as a data base from which to pinpoint the most critical areas of the SPS program. A set of criteria was developed as a guide in evaluating the issues. These criteria consisted of categorizing the issues into one of the following three levels of criticality:

- Level 1 - Potential "show-stoppers"
- Level 2 - Potential of serious impact
- Level 3 - Potential of undesirable impact

A Level 1 issue was defined as an issue which, if a negative result were determined or if there was a failure to resolve the issue, could result in the SPS program being labeled as unfeasible. If these issues were not resolved or a work-around developed, they would be labeled as "showstoppers" and as a result the SPS program would more than likely be discontinued. For example, if the capital needed to finance materials, equipment, labor, etc., could not be obtained, the SPS program would not get to the operational phase.

A Level 2 issue was defined as an issue which, if a negative result were determined or if there was a failure to resolve the issue, could result in serious impact to the SPS program. For example, if the solar cell cost was significantly higher than current projections, there might be serious impacts to the SPS program since a significant portion of the satellite cost is attributed to the cost of solar cells.

A Level 3 issue was defined as an issue which, if unresolved, would result in undesirable impacts to the SPS program. For example, crew safety is considered a necessity but if the current plans for crew safety could not be achieved,

Table 1.1-1. Candidate Areas of Concern

PHASE CONTROL
 DC-RF CONVERTERS
 WAVEGUIDES
 SHUTDOWN/START-UP OF MW ANTENNA
 ANTENNA POINTING AND CONTROL
 SATELLITE POINTING AND CONTROL
 POWER DISTRIBUTION SWITCHING
 POWER CONDUCTION
 POWER TRANSFER ACROSS ROTARY JOINT
 MATERIAL DEGRADATION
 RECTENNA OPERATIONS
 RECTENNA INFORMATION MANAGEMENT SYSTEMS
 RECTENNA/UTILITY INTERFACE
 RECTENNA POWER DISTRIBUTION AND CONTROL
 LOGISTICS TO LAUNCH SITE(S)/RECTENNA SITES
 LAUNCH RATES
 LAUNCH VEHICLE SIZE
 SAFETY AND CONTROL OF LAUNCH VEHICLES
 OTV PERFORMANCE
 LIGHTWEIGHT BLANKET PRODUCIBILITY (MASS, EFF., COST)
 SATELLITE INFORMATION MANAGEMENT PROCESSING
 FAILED HARDWARE (ON SPS) DISPENSATION
 SPARES MASS
 POWER CONVERSION DEVICES LIFE/DEGRADATION/MAINTENANCE
 MICROWAVE ELEMENT LIFE/FAILURE RATES/MAINTENANCE
 RECTENNA ELEMENT LIFE/FAILURE RATES/MAINTENANCE
 ATTITUDE CONTROL AND STATIONKEEPING THRUSTER LIFE
 OPERATIONS/MAINTENANCE COST
 REFLECTOR FILMS DEGRADATION
 DC-DC EFFICIENCY
 ASSEMBLY RATES
 CREW SIZES
 FABRICATION AND ASSEMBLY LOCATIONS
 MAN/MACHINE PRODUCTIVITY
 PRODUCTIVITY EVA REQUIREMENTS
 CREW SAFETY
 ORBITAL STAY TIME
 SPACE CONSTRUCTION PROCESSES
 SPACE MAINTENANCE PROCESSES
 OPERATIONAL COMPLEXITY
 PROPELLANT RESUPPLY IN ORBIT
 CONSTRUCTION BASE LOGISTICS

RELIABLE FLUID CONTAINMENT
 REFLECTOR FILMS DEVELOPMENT
 REFLECTOR FILMS FLATNESS CONTROL
 HIGH-TEMPERATURE HEAT EXCHANGERS
 PHYSICAL SPACE AT GEO
 SPACE COLLISIONS
 RESOURCE LIMITS
 GEOGRAPHIC LOCATION OF RAW MATERIALS
 ENERGY BALANCES
 OIL USAGE (LAUNCH VEHICLES)
 RECTENNA LAND REQUIREMENTS
 LAND USE NEAR RECTENNA
 LAUNCH SITE(S) LAND REQUIREMENTS
 RECOVERY FACILITIES (LAUNCH VEHICLES)
 LAUNCH VEHICLE REFURBISHMENT
 GSE REQUIREMENTS
 PAYLOAD PACKAGING DENSITY
 TRANSPORTATION COST TO ORBIT
 SPS ON-BOARD ENERGY STORAGE
 ON-GROUND POWER FLUCTUATIONS AND OUTAGE
 COMPETITIVE COST OF ENERGY
 CONSTRUCTION BASE TRANSFER
 FRONT-END DDT&E
 CAPITAL INVESTMENTS
 ENGINEERING AVAILABILITY
 MANUFACTURING CAPABILITIES/DEMANDS
 TECHNOLOGY/CAPACITY
 FUTURE NASA PROGRAMS
 DEVELOPMENT PROGRAM SCHEDULE AND SCHEDULE FLEXIBILITY
 DESIGN COMPLEXITY AND PROGRAM MANAGEMENT COMPLEXITY
 INTERNATIONAL EMBARGOES/CRISES/ETC.
 SECURITY
 SPACE RADIATION LIMITS TO CREWS
 MW BEAM, ON-ORBIT MAINTENANCE PERSONNEL
 ENVIRONMENTAL EFFECTS OF LAUNCH VEHICLES
 PLASMA INTERACTIONS
 HIGH-VOLTAGE SPACE CHARGING
 INCIDENT MW RADIATION
 LEO-TO-GEO TRANSFER OF LARGE STRUCTURE
 ELECTRIC THRUSTER PERFORMANCE
 MICROWAVE BEAM DISPERSION ANALYSIS
 VOLTAGE AND CURRENT REGULATION



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then surely work-arounds could be developed to provide the safety requirements without significantly impacting the program.

These issues, as shown in Table 1.2-1, sub-divided based on considerations related to economic viability, technical feasibility, and environmental acceptability. In the area of economic viability, three top-level considerations were identified: (1) the ability to achieve cost targets, (2) the cost of other energy sources, and (3) the limitations of key resources (material or human).

Table 1.2-1. Areas of Concern

CRITICALITY	ECONOMIC VIABILITY	TECHNICAL FEASIBILITY	ENVIRONMENTAL ACCEPTABILITY
LEVEL 1 POTENTIAL SHOW- STOPPER	CAPITAL INVESTMENTS TRANSPORTATION COST TO ORBIT FRONT END DDT&E RESOURCE AVAILABILITY COMPETITIVE COST OF ENERGY	PHASE CONTROL LAUNCH RATES ANTENNA POINTING & CONTROL ORBITAL ASSEMBLY	MICROWAVE EXPOSURE STANDARDS MW IMPACT ON OZONE LEVELS & UV RADIATION LAUNCH VEHICLE IMPACT ON OZONE LAYER SPACE RADIATION LIMITS TO CREW
LEVEL 2 POTENTIAL SERIOUS IMPACT	LIGHTWEIGHT BLANKET PRODUCTIBILITY QTV PERFORMANCE CHARACTERISTICS OPERATIONS/MAINTENANCE COST MW ELEMENT LIFE/FAILURE RATES POWER CONVERSION DEVICES LIFE/ DEGRADATION ATTITUDE CONTROL & STATIONKEEPING THRUSTER PERFORMANCE & LIFE RECTENNA LAND REQUIREMENTS SYSTEMS COMPLEXITY PAYLOAD PACKAGING DENSITY REFLECTOR FILM DEVELOPMENT ON BOARD ENERGY STORAGE	DC-RF CONVERTERS WAVEGUIDES SATELLITE POINTING & CONTROL SHUTDOWN/START-UP OF MW ANTENNA LAUNCH VEHICLE SIZE SPACE MAINTENANCE PROCESSES ORBITAL TRANSFER OF LARGE SPACE STRUCTURES POWER DISTRIBUTION SWITCHING TECHNOLOGY / CAPACITY HIGH TEMPERATURE HEAT EXCHANGERS PROPELLANT RE-SUPPLY IN ORBIT RELIABLE FLUID CONTAINMENT REFLECTOR FILMS FLATNESS CONTROL VOLTAGE & CURRENT REGULATION MICROWAVE BEAM DISPERSION ANALYSIS	PUBLIC ACCEPTANCE OF SPS RFI EMI HIGH VOLTAGE SPACE CHARGING PLASMA INTERACTIONS LAUNCH VEHICLE NOISE & SONIC BOOMS GEO ORBIT AVAILABILITY SPACE COLLISIONS ENERGY BALANCES QTV EMISSIONS ORIGINAL PAGE 1 OF POOR QUALITY
LEVEL 3 POTENTIAL UNDESIRABLE IMPACT	ASSIGNMENT OF MW FREQUENCY LAUNCH VEHICLE RECOVERY/REFURBISH ON GROUND POWER FLUCTUATIONS & STORAGE REFLECTOR FILMS DEGRADATION RECTENNA ELEMENT LIFE/FAILURE RATES/ MAINTENANCE OIL USAGE (LAUNCH VEHICLES) LAUNCH SITE(S) LAND REQUIREMENTS INTERNATIONAL EMBARGOS/CRISES USE REQUIREMENTS SECURITY REUSABLE PARTS	CONSTRUCTION BASE LOGISTICS POWER CONDUCTION TERRESTRIAL LOGISTICS FUTURE NASA PROGRAMS RECTENNA OPERATIONS DEVELOPMENT PROGRAM SCHEDULE & FLEXIBILITY RECTENNA/UTILITY INTERFACES ENGINEERING AVAILABILITY RECTENNA INFORMATION MANAGEMENT SYSTEMS SATELLITE INFORMATION MANAGEMENT PROCESSING MANUFACTURING CAPABILITIES/DEMANDS	SAFETY & CONTROL OF LAUNCH VEHICLES ORBITAL CREW SAFETY POLLUTANTS FROM MINING & MANUFACTURING TERRESTRIAL WORKERS HEALTH & SAFETY MW EFFECT ON ECOLOGY, SOIL, WATER, AND ATMOSPHERE POLLUTANTS FROM TRANSPORTATION OPERATIONS FAILED HARDWARE (ON SPS) DISPENSATION LAND USE NEAR RECTENNA

In the area of technical feasibility, the major concerns are the availability of the required technology in the SPS time period and the ability of the system, subsystem, or elements to meet performance goals. Finally, the impact of the environment on the satellite and the ability to meet existing or potential environmental standards was considered to be an area where issues may exist.

Each of the issues, as identified in the previous section, was placed into one of these three areas: economic, technical, or environmental. For some issues there might be a concern from more than one viewpoint. For example, there are both economic and technical questions with regard to space construction processes. However, it is believed at this time that the technical requirements are of potentially greater significance than the economic concerns. Therefore, the issue of space construction processes was considered to be primarily one of a technical nature and as a result was placed under the heading of technical feasibility.



1.3 TECHNICAL REQUIREMENTS

The areas of concern (shown in Table 1.2-1) include each issue by topic. A brief statement as to what makes each of the Level 1 and Level 2 issues an area of concern is given in Tables 1.3-1 and 1.3-2, respectively. A more elaborate description of each of the Level 1 issues is given in this section.

Table 1.3-1. Technical Requirements - Level 1 Issues

AREA OF CONCERN	TECHNICAL REQUIREMENTS
CAPITAL INVESTMENTS	NECESSARY CAPITAL MUST BE AVAILABLE TO FINANCE MATERIALS, EQUIPMENT, OPERATIONS, ETC. OF SPS.
TRANSPORTATION COST TO ORBIT	LAUNCH OPERATIONS AND TURNAROUND COST MUST BE MINIMIZED TO REDUCE SPS TRANSPORTATION COST.
FRONT-END DDT&E	NECESSARY CAPITAL MUST BE AVAILABLE TO FINANCE REQUIRED VERIFICATION ACTIVITY AND FRONT-END DEVELOPMENT
RESOURCE LIMITS	DEMAND FOR RESOURCES SHOULD NOT EXCEED AVAILABILITY
COMPETITIVE COST OF ENERGY	SPS SHOULD NOT BE SIGNIFICANTLY MORE COSTLY TO CONSUMERS THAN OTHER AVAILABLE ENERGY SOURCES.
PHASE CONTROL	ABILITY TO ACHIEVE FAIL-SAFE PHASE CONTROL SUBSYSTEM PERFORMANCE.
LAUNCH RATES	MULTIPLE LAUNCHES PER DAY MUST BE ACHIEVABLE. REQUIRED LAUNCH RATES MUST BE CREDIBLE FOR SIZE AND TYPE OF HLLV. LAUNCH TURNAROUND TIMES NEED TO BE MINIMUM TO REDUCE FLEET SIZE.
ANTENNA POINTING AND CONTROL	ABILITY TO ACHIEVE FAIL-SAFE HIGHLY ACCURATE POINTING SYSTEM PERFORMANCE.
SPACE CONSTRUCTION PROCESSES	DEVELOPMENT OF TECHNIQUES TO MANUFACTURE, ASSEMBLE, ALIGN, INSPECT AND REPAIR LARGE SPACECRAFT IN ORBIT.
INCIDENT MW RADIATION	INDUCED IONOSPHERIC, RFI, AND BIOLOGICAL EFFECTS ON OTHER USES MUST BE HELD TO ACCEPTABLE QUANTIFIABLE LEVELS.

1.3.1 ECONOMIC VIABILITY - LEVEL 1 ISSUES

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Capital Investments

One great challenge of SPS is economic. Therefore, the level of investments in plant and equipment expenditures for each of the full-scale SPS's can be an influencing factor in economic viability of the program. Current projections indicate a high percentage of the overall SPS cost will be needed for the procurement, launch, and installation of SPS satellites and ground stations. This cost and phasing extends from DDT&E to IOC (Initial Operating Capability) and includes the replacement of capital investments over the life of the SPS program. Detail elements which make up these satellites and ground station costs are represented in SPS production, assembly, installation, launch/transportation, test, and capital asset replacements. Optimized programmatic considerations and operational approaches will be an important ingredient in the availability and source of funding for an operational SPS project.

Transportation Cost to Orbit

Previous studies by the NASA and industry have shown the dependence of SPS economic viability on achieving low space transportation costs. The "efficiency" of space transportation systems in delivering cargo to geosynchronous equatorial



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Table 1.3-2. Technical Requirements - Level 2 Issues

AREA OF CONCERN	TECHNICAL REQUIREMENT
DC-RF CONVERTERS	CONVERTER SELECTION AND DEVELOPMENT, 30-YR MTBF HIGH-PHASE STABILITY, ACCEPTABLE NOISE LEVEL
HIGH-VOLTAGE SPACE CHARGING	CONTROLLED SURFACE CONDUCTIVITY REQ'D TO REDUCE DIFFERENTIAL SURFACE CHARGING
LIGHTWEIGHT BLANKET PRODUCIBILITY	ABILITY TO MASS PRODUCE SOLAR CELLS WHICH ARE LIGHTWEIGHT AND HAVE HIGH EFFICIENCY AND LOW COST
PLASMA INTERACTIONS	POWER LOSS AT LEO PREVENTS OPERATION ABOVE 300 TO 400 V. POWER LOSS AT GEO THEORETICALLY LOW, BUT VERIFICATION REQUIRED
WAVEGUIDES	WAVEGUIDE SELECTION AND DEVELOPMENT FOR 30-YR STABILITY IN ORBITAL ENVIRONMENT
OTV PERFORMANCE	HIGH-PERFORMANCE ORBITAL TRANSFER VEHICLE FOR THE LEO TO GEO TRANSFER
SATELLITE POINTING AND CONTROL	ABILITY TO POINT & CONTROL LARGE AREA/MASS POWER CONVERSION DEVICES
ASSEMBLY RATES	MINIMIZE SATELLITE ASSEMBLY TIMES BY MAXIMIZING MAN-MACHINE PRODUCIBILITY, DESIGNING PROCESSING FOR NEAR-CONTINUOUS OPERATIONS, ADDING MACHINES, AND INCREASING FACILITIES
ENVIRONMENTAL EFFECTS OF LAUNCH VEHICLES	LIMIT HLLV PARTICULATE AND GASEOUS EMISSIONS AND ACOUSTIC LEVELS TO EPA RECOMMENDED STANDARDS FOR REGIONS COVERED DURING LAUNCH
SHUTDOWN/STARTUP OF MW ANTENNA	ABILITY TO SHUT DOWN AND START UP MICROWAVE ANTENNA AS A RESULT OF OCCULTATION, MAINT., ETC., WITH NO DETRIMENTAL EFFECTS ON SYSTEM PERFORMANCE AND RELIABILITY; ABILITY TO MINIMIZE STARTUP TIME
OPERATIONS/MAINTENANCE COST	DETERMINATION OF OPERATIONS AND MAINTENANCE REQUIREMENTS AND IMPACT ON USER CHARGES
POWER TRANSFER ACROSS ROTARY JOINT	ABILITY TO TRANSFER HIGH CURRENT ACROSS SLOW ROTATING INTER-FACE; VERY HIGH RELIABILITY REQUIRED TO OFFSET POTENTIAL SINGLE-POINT FAILURE
MICROWAVE ELEMENT LIFE/FAILURE RATES/MAINT.	DEVELOPMENT OF DC-RF CONVERTERS, FILTERS, WAVEGUIDES, AND PHASE CONTROL SUBSYSTEM ELEMENTS FOR RELIABLE OPERATION FOR 30 YEARS
LAUNCH VEHICLE SIZE	ABILITY TO DEVELOP, OPERATE, HANDLE, AND REFURBISH VERY LARGE VEHICLES IN SHORT TURNAROUND TIME
SPACE MAINTENANCE PROCESSES	DEVELOPMENT OF THE PROCESSES REQ'D FOR MAINTENANCE OF THE TOTAL SPS SYSTEM
PHYSICAL SPACE AT GEO	LIMITATIONS OF THE PHYSICAL SPACE AVAILABLE AT GEO DUE TO A MULTITUDE OF GEO SATELLITES AND MISSION; UNILATERAL USE OF THIS SPACE POSES INTERNATIONAL ISSUES
LEO-TO-GEO TRANSFER OF LARGE STRUCTURES	ABILITY TO CONTROL LARGE STRUCTURES IN LEO AND TO TRANSFER STRUCTURE TO GEO
MATERIAL DEGRADATION	ABILITY TO WITHSTAND OPERATING ENVIRONMENT--RADIATION, MICRO-METEOROID IMPACTS, THERMAL CYCLING, POTENTIAL OUTGASSING OF MATERIALS
POWER DISTRIBUTION SWITCHING	ABILITY & IMPACT OF SWITCHING LARGE CURRENT & VOLTAGE LEVELS IN SPACE



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Table 1.3-2. Technical Requirements - Level 2 Issues (Cont.)

AREA OF CONCERN	TECHNICAL REQUIREMENT
FABRICATION AND ASSEMBLY LOCATION	OPEN ISSUE OF LEO VS. GEO CONSTRUCTION LOCATION WHICH SIGNIFICANTLY IMPACTS TOTAL SYSTEM CONSTRUCTION AND DDT&E DEVELOPMENT PLANNING STRATEGY
HIGH-TEMP HEAT EXCHANGERS	RELIABLE OPERATION & FLUID CONTAINMENT OF RADIATORS, COOLERS, RECUPERATORS, ETC., IN ORBITAL ENVIRONMENT FOR 30-YR LIFE
TECHNOLOGY/CAPACITY	ADVANCEMENT OF TECHNOLOGY IN MULTIDISCIPLINE AREAS TO DESIRABLE LEVELS
POWER CONVERSION DEVICES LIFE/DEGRADATION/MAINT.	ABILITY TO WITHSTAND OPERATING ENVIRONMENT--TRAPPED RADIATION, SOLAR FLARE EVENTS, IMPACTS, OPERATING TEMP & THERMAL CYCLING; ABILITY TO PERFORM MAINTENANCE WHILE OPERATIONAL
ATTITUDE CONTROL & STATION-KEEPING THRUSTER LIFE	MTBF OF THRUSTERS FOR 30-YR LIFE WITH OPERATING CYCLES, OCCULTATIONS, ETC.
SPACE COLLISIONS	POLITICAL & TECHNICAL PROBLEMS ASSOCIATED WITH POTENTIAL COLLISIONS OF SPS AND OTHER SATELLITES
RECTENNA LAND REQUIREMENTS	LOCATING & ACQUIRING THE NECESSARY RECTENNA LAND
DESIGN COMPLEXITY & PROGRAM MGMT COMPLEXITY	ABILITY TO EFFICIENTLY MONITOR & CONTROL THE DESIGN, DEVELOPMENT & IMPLEMENTATION OF SUCH A LARGE COMPLEX PROGRAM
OPERATIONAL COMPLEXITY	COMPLEXITY OF MONITORING AND SERVICING SEVERAL LARGE LONG-LIFE SPACECRAFT
ENERGY BALANCE	COMPARISON OF ENERGY AVAILABLE FROM SPS VS. ENERGY REQUIRED TO BUILD AND MAINTAIN
DC-DC EFFICIENCY	ABILITY TO ACHIEVE HIGH-EFFICIENCY WITH THE MICROWAVE CONVERSION, TRANSMISSION AND RECEPTION SYSTEMS
PROP. RESUPPLY IN ORBIT	ABILITY TO SAFELY TRANSFER PROPELLANTS IN ORBIT
P/L PACKAGING DENSITY	SENSITIVITY OF TRANSP. COST TO PAYLOAD PACKAGING DENSITY
MAN/MACHINE PRODUCTIVITY	ASSIGNMENT, PRODUCTIVITY, & INTERACTION OF RESPONSIBLE TASKS FOR BOTH MAN AND MACHINES IN ORBIT
SPACE RADIATION LIMITS TO CREW	SPACE RAD. LIMITS TO ORBITAL PERSONNEL & THE RESULTING IMPACT TO CREW STAYTIME, NO. OF CREW REQ'D, TRAINING OF CREWS; FACILITIES TO MINIMIZE RADIATION LEVELS ON CREW
REFLECTOR FILMS DEVELOPMENT	ABILITY TO ADVANCE REFLECTOR FILM DEVELOPMENT FOR LIGHTWEIGHT, HIGHLY REFLECTIVE, DURABLE, LARGE AREA REFLECTIONS
GEOGRAPHIC LOCATION OF RAW MATERIALS	LOCATION (WITHIN & EXTERNAL TO U.S.) OF MATERIAL QUANTITIES NEEDED
ELECTRIC THRUSTER PERFORMANCE	SPECIFIC IMPULSE, MASSES, OPERATIONAL CHARACTERISTICS AND MTBF OF ELECTRIC THRUSTERS
VOLTAGE & CURRENT REGULATION	REQMTS IMPOSED BY VOLTAGE & CURRENT REGULATION ON SOLAR ARRAY & MICROWAVE SUBSYSTEMS, AND ABILITY TO MEET REQUIREMENTS
MW BEAM DISPERSION ANALYSIS	ABILITY TO DEFOCUS, DISPERSE, AND SHUT DOWN THE MICROWAVE PWR BEAM SO AS NOT TO IMPOSE UNDESIRABLE SIDE EFFECTS
RELIABLE FLUID CONTAINMENT	ABILITY TO RELIABLY CONTAIN LARGE VOLUMES OF FLUID IN SUCH SYSTEMS AS RADIATORS, PROPELLANTS, ETC., FOR LONG PERIODS OF OPERATION
SPARES MASS	POTENTIAL IMPACT ON TRANSP., STORAGE, HANDLING, ETC., OF LARGE MASSES OF SPARES
REFLECTOR FILMS FLATNESS CONTROL	ABILITY TO CONTROL LARGE SURFACE AREAS OF REFLECTIVE SURFACES SO AS TO MINIMIZE UNDESIRABLE IMPACTS SUCH AS SIZING STRUCTURE FOR REFLECTOR TENSIONING, NON-UNIFORM ILLUMINATION, ETC.
SPS ON-BOARD ENERGY STORAGE	COMM., DATA HANDL., ATTITUDE CONTROL, ETC., REQUIREMENTS DURING PERIODS OF OCCULTATION
ORBITAL STAYTIME	POTENTIAL ECONOMIC IMPACTS OF LIMITED ORBITAL STAYTIMES FOR ASSEMBLY AND MAINTENANCE PERSONNEL



orbit (GEO) centers on the earth launch vehicle (HLLV). Studies have clearly indicated the need for totally reusable HLLV concepts designed for many reuses. In a program with the payload-to-orbit demands of an SPS, operations cost dominates the percentages that are apportioned to dollars per kilogram to orbit, via., upward to 85 percent. Thus, operations costs (i.e., launch, recovery, refurbishment, and prelaunch operations) are the key driver of space transportation economics. Typically, the larger the booster--and the payload--the lower the costs. This is true up to some reasonable size limit yet to be determined. The size limit may be determined by environmental considerations, facility size location, operational versatility, or combinations of these.

Front-End DDT&E

Preliminary estimates of front-end development costs for the SPS system indicate they may be higher than competing energy sources, but with SPS having lower operational costs. This high front-end development cost results from the heavy mass transfer-to-orbit requirements imposed by the very large size and weight of prototype and operational SPS which dictate relatively early development of large-capacity orbital delivery and transfer vehicles to reduce the cost per pound to LEO and GEO. A whole new industry for space construction must be developed including trained workers, special tools, procedures, safety standards, orbital living quarters, etc. The cost of stepping up production to meet the requirements of large prototype satellites must also be considered along with the cost of manufacturing large quantities of material.

Development planning to minimize such costs in the early phases results in non-prototypical test activities and implies a higher risk system verification program.

Resource Limits

Materials for manufacturing the solar arrays, except for gallium (Ga), are readily available and do not constitute a large percentage of the total materials that are mined or manufactured. There has been some concern expressed for the availability of Ga. However, the availability of Ga appears to be sufficient for the needs of SPS when utilizing the concept of a 25- μ m cell or a 5- μ m GaAs junction on an Al_2O_3 substrate. It appears that sufficient quantities could be obtained from the mining or projected mining of bauxite when the Al_2O_3 substrate is used. However, in order to obtain the Ga from the bauxite, the efficiency of the extraction process will have to be increased from 30% to 80%, and new facilities developed requiring approximately \$500K to \$750K of capital per metric ton of yearly capacity. The refining process for obtaining increased production efficiency has to be developed and demonstrated. Also, the raising of capital to build the facilities for refining the Ga is a major economic issue.

Resource limits could be a concern relative to the space transportation if a LOX/RP-fueled launch vehicle were used. This would place added demands on the already rapidly depleting resource (i.e., oil) since the projected usage rate for the space transportation system would be greater than 20 percent of the total world airline consumption of 1975. This resource limit is not expected to impact the SPS transportation system since the primary concepts are a LOX/LH₂ engine system and a hydrogen-fueled airbreathing engine system.



Competitive Source of Energy

At the current time, there are several potential methods of producing electricity during the time period proposed for SPS. These include such categories as fossil fuel, nuclear, wind, geothermal, and ground-based solar. Within each of these categories there may be several options or variations. If any of these options are categories are to remain economically viable they must not be significantly more expensive than the other options, provided that the most economical options will produce the required levels (kW-hr) of electricity, and be socially and environmentally acceptable.

1.3.2 TECHNICAL FEASIBILITY - LEVEL 1 ISSUES

Phase Control

The Microwave Power Transmission System (MPTS) subarray phase front control subsystem must provide high-accuracy beam pointing and focusing of a high-power microwave beam in the presence of: a non-homogeneous, time-varying atmosphere and ionosphere; thermal deformation of the array waveguide and structure; and phase variation of transmission lines, converters, and phase shifters. Safety considerations, to limit high-power densities to acceptable values outside the receiving antenna area, require positive control over beam focusing and pointing during steady-state and transient conditions. High overall efficiency requires both accurate beam pointing and proper focus. Phase control, being essential to beam pointing as well as focusing, must be shown to be reliable for power user and safety purposes.

Launch Rates

In terms of numbers of space launches per unit time, the demands of the SPS program will exceed contemporary figures by orders of magnitude. Scenarios indicate that multiple daily launches of HLLV's will occur during the operational program. In addition, HLLV turnaround times will have to be very short in order to minimize fleet size and facility requirements. Thus, the requirements of stack-up, checkout, launch, recovery, and refurbishment imposed by multiple daily launches suggest new concepts for launch operations.

Antenna Pointing and Control

Microwave beam defocusing and pointing errors must be prevented by a fail-safe, highly accurate, pointing system. Beam defocusing, if uncontrolled, could increase the cumulative diffuse radiation from the system. Major pointing errors are also clearly intolerable. However, a limited variation in beam pointing can be accepted by increasing the rectenna and exclusion area. For these reasons, it is evident that a fail-safe capability to point and control the microwave transmission is an essential requirement for the system's acceptability, and is, of course, planned.

Space Construction Processes

Due to the large size of the SPS, orbital assembly will be required. However, in this area there is relatively little existing data on which to



build. Considerable verification effort is therefore required in order to develop and verify the space construction processes. Even some of the basic tasks have yet to be defined. These include long-term capabilities and limitations of humans to perform EVA, and robot/teleoperator mechanisms to perform orbital construction tasks. The fastening and joining techniques of orbit assembled structures is unknown. Other concerns include, but are not limited to: alignment/adjustment procedures; materials technology; deployable versus orbit-fabricated structure; variations during assembly such as mass, center of gravity, stiffness, etc.; construction equipment development; thermal torques; thruster loads; docking loads; gravity-gradient torques; and integration of subsystems with the structure.

1.3.3 ENVIRONMENTAL IMPACT - LEVEL 1 ISSUES

Incident Microwave Radiation

Microwave-induced ionospheric effects are considered to be one of the major constraining key issues. Ionospheric effects are potentially of great significance and, hence, require an early technology program to quantify the impact of and to establish acceptable ionospheric changes as a result of microwave transmission. Theoretical evidence has indicated a possibility of causing ionospheric irregularities above 23 MW/cm^2 , and a power density of 50 MW/cm^2 is believed to be near the threshold for ionospheric modification. Although this density would be localized to the center of the beam, it might gradually affect a wide region of the ionosphere over time. Such interactions of the beam with the plasma in the D, E, and F layers of the ionosphere must be studied to determine the potential interference on terrestrial, airborne and spaceborne communications, navigation, and radar systems, as well as on lower-altitude satellite systems.

Another concern with the microwave beam is its potential direct effects on humans and biota in the ground area and airspace near the receiving facility. There is considerable controversy, however, over the limits that should be set for the allowable power density, since the effects of low-level microwave radiation is relatively unknown.

Indirect radiation from the rectenna could also produce significant RFI. Reflected microwave, generated harmonics, high-frequency radiation due to dc power switching, etc., could potentially contribute to the problem in a wide spectrum of other system operating frequencies.

The direct microwave radiation power density could be at a level potentially significant as an RFI source throughout the visible hemisphere. This factor could be of major importance to SPS go/no-go continuation decisions--especially if a large number of satellites was established with cumulative effects.

Attention has also been paid to the local heating of the ground and atmosphere that would arise from the waste heat radiated at the rectenna. It has been suggested that weather patterns could be affected by both this effect and the direct heating of the air by the microwave beam and its reflections from the rectenna. However, some limited analysis indicates that the excess heat



is negligible compared to that of a city, for example, and is only about one-tenth of that arising from coal or nuclear plants; so, except possibly in an area such as a desert where the ecology is particularly fragile and the weather perhaps particularly sensitive to local effects, little concern now seems warranted on this problem.

1.4 RESOLUTION OF KEY ISSUES

1.4.1 EVALUATION LOGIC

Each of the issues was reviewed in an attempt to determine the necessary steps required for resolution of the issues. The program philosophy for issue resolution was categorized into three steps that include analysis, ground demonstration, and space verification. Since it is known that each of these succeeding steps becomes more costly, the philosophy was to obtain the maximum benefits at the lower steps.

Each issue was studied independently, and an effort was devoted toward defining a top-level sequence of events that would lead toward resolution of that issue. Later, these issues were then integrated into a composite verification program.

Some of the issues can essentially be resolved with analysis, and will not require ground or space verification. For example, the issue of capital investments can be resolved by analysis. Certainly, the ground and space verification of components, subsystems, and systems will contribute indirectly by increasing confidence in the SPS program and thereby help to secure the necessary capital for financing materials equipment, etc. However, the direct contribution to resolving the issue will be accomplished through analysis.

Other issues can be resolved by a combination of analysis and ground demonstration; for example, the issue of solar cell cost can be resolved without going to space. On the other hand, there are some issues which cannot be satisfactorily resolved without utilizing space verification. Relatively little is known about the orbital assembly requirements, techniques, equipment, etc., that will be needed for orbital assembly of the large spacecraft. There are several questions that cannot be satisfactorily resolved by analysis and ground demonstration due to the unique environment (zero gravity, low vacuum, thermal cycling, etc.) of space. Typical task elements for Level 1 key issue resolution are shown in Table 1.4-1.

The next phase was to determine how well the issue could be resolved with specific or identifiable items of hardware; for example, how much of the issue could be resolved if the sortie missions were available, or how much of the issue could be resolved with a 5-GW prototype SPS?

Since a wide range of options is available, an incremental program was hypothesized as a first iteration in establishing the verification program. Figure 1.4-1 illustrates the orbital electric power requirements as a function of time, ranging from the 25-kW power module to a 1- to 5-GW prototype SPS. Since there are several orders of magnitude difference in the end points,



Table 1.4-1. Typical Task Elements for Key Issue Resolution

KEY ISSUES	ANALYSIS	GROUND DEMONSTRATION	SPACE VERIFICATION
CAPITAL INVESTMENTS	- ESTABLISH FUNDING & ECONOMIC FEAS. - IDENTIFY OPTIMUM FUNDING ARRANGEMENT & ORGANIZATIONAL STRUCTURE - OBTAIN GOVT/UTILITY COMMITMENT AND INVOLVEMENT - IDENTIFY LEVELS OF INVESTMENT - FORM NATIONAL SPS ORGANIZATION - DETAIL ECONOMIC BENEFITS IMPACTS AND RESOURCES - OBTAIN RESOURCE ALLOCATION - FUND PLANTS, EQUIP., OPERATION, ETC.	ORIGINAL PAGE IS OF POOR QUALITY	
TRANSPORTATION COST TO ORBIT	- OPERATIONS, ANALYSES OF LAUNCH, RECOVERY, REFURB COST IN CONCERT WITH TRANSPORTATION SYST STUDIES - DEVELOP COST MODELS		
FRONT-END DDT&E	- PREREQUISITE SYSTEM POINT DESIGN SELECTION - TECHNOLOGY ADVANCEMENT PLANNING - VERIF TEST ARTICLE DEFINITION - MASS FLOW REQMTS DEFINITION - EVALUATION OF GRND & SPACE TEST		
RESOURCE LIMITS	- ANALYZE MASS FLOW DEMANDS - DEFINE RESOURCE & PRODUCTION LIMITS - CONCEPTUALIZE FACILITY REQUIREMENTS		
COMPETITIVE COST OF ENERGY	- IDENTIFY CONSUMER COST OF ENERGY FROM SPS & AVAILABLE COMPETITIVE SOURCES - COMPARATIVE EVALUATION		
PHASE CONTROL	- CONCEPTUAL DESIGN - SUBSYSTEM SELECTION	GRND-TO-GRND AND GRND-TO-SPACE PHASE CONTROL HIGH-POWER FEASIBILITY	- SUBSCALE SPACE-TO-GRND PHASE CONTROL DEMONSTRATION - HIGH-VOLTAGE PLASMA EFFECTS ASSESSED
LAUNCH RATES	- HLLV CONCEPT ANALYSIS STUDIES - SELECT HLLV CONCEPT - ANALYTICAL MODELS - LAUNCH OPERATIONS ANALYSIS		
ANTENNA POINTING AND CONTROL	- CONCEPTUAL DESIGN - SUBSYSTEM SELECTION	GRND-TO-GRND & GRND-TO-SPACE LARGE AREA/MASS CONTROL FEAS.	LARGE-SCALE OPN IN ACTUAL ENVIRONMENT
SPACE CONSTRUCTION PROCESSES	- STUDY OPTIONS - DEFINE PROCESSES - CONCEPTUAL DESIGNS	- GRND TEST OF JOINT DESIGN, ASSY TECHNIQUES, ALIGN., ETC. - NEUTRAL BUOYANCY SIMULATION	- DEMONSTRATE PROCESSES IN SPACE - DEMONSTRATE LARGE-SCALE ASSEMBLY
INCIDENT MW RADIATION-IONOSPHERIC EFFECTS	- SELECTION OF POWER DENSITY LEVEL - SCALED IONOSPHERIC HEATING EFFECTS TESTED	- GRND-TO-GRND HIGH-POWER RFI TEST ASSESSMENT - HIGH-POWER D/F LAYER HEATING EFFECTS, EXPMTL DATA	- HIGH-POWER RFI TEST ASSESSMENTS - D/F LAYER HEATING EFFECTS

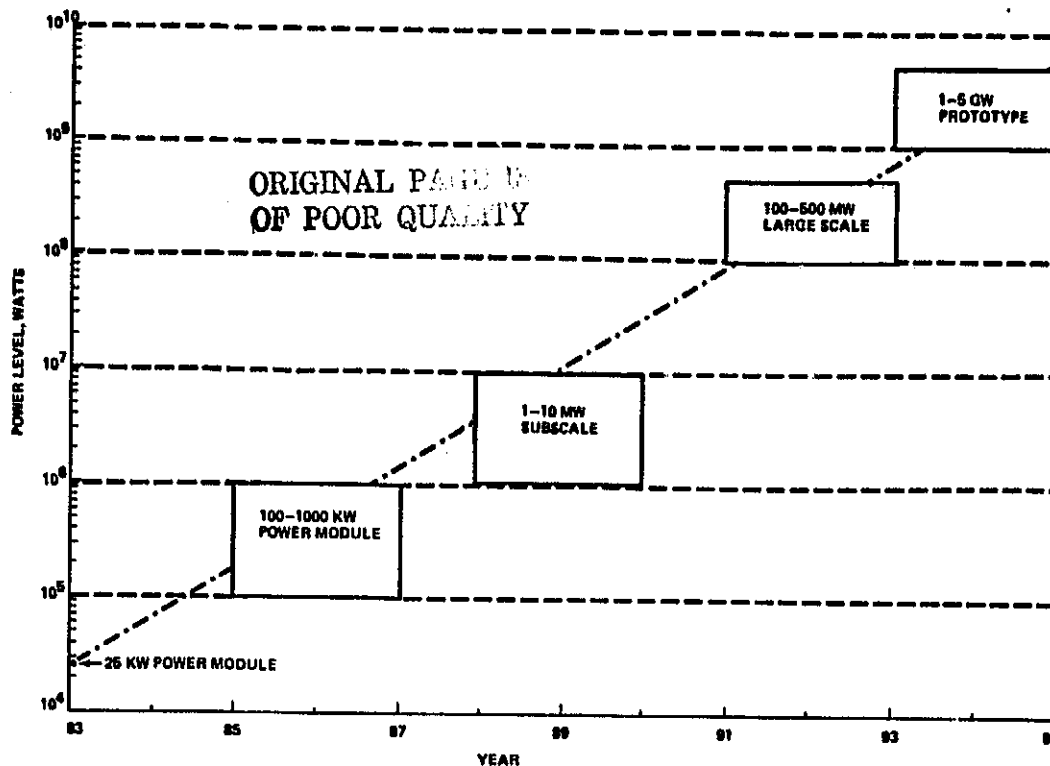


Figure 1.4-1. SPS Space Verification Program Options

several intermediate elements were added to the preliminary program scenario. This insertion does not imply that all are required. Rather, the purpose was initially to define a range of options and to later establish which would yield the greatest contribution at the minimum cost. For example, it is known that some issues cannot be completely (100%) resolved short of a 5-GW prototype; however, these might be 95% resolved with a 10-MW subscale SPS. In this case, there would be little technical advantage for implementing the larger system since the additional cost for the relatively small return would not be cost-effective.

1.4.2 RATING METHODOLOGY

A numerical rating was defined to show the relative contribution of each program element toward resolution of the issues as shown in Table 1.4-2. The numerical ratings range from 0 to 10, with 0 referring to no contribution and 10 meaning that the issue was completely resolved. The numerical rating shows the cumulative resolution, or how much of the issue has been resolved at a specific point.

It was assumed that analysis, ground demonstration, sorties, and extended sortie missions with the 25-kW power module would be available and all other elements were considered optional. Therefore, for these first four elements, the individual contribution of each element is its numerical rating minus the numerical rating attributed to the previous element. For all program elements after the 25-kW power module, the individual contribution was referenced back from the power module. If the data had been established in the more conventional

Table 1.4-2. SPS Verification Activity

AREA OF CONCERN	POTENTIAL RESOLUTION												
	ANALYSIS	GROUND DEMO	LEO SORTIES	25-KW PM	COMPOSITE ANTENNA LEO	30 KW SMALL SATELLITE GEO	DIAGNOSTIC ANTENNA	100 - 1000 KW POWER MOD		1 - 10 MW TEST ART.		100 - 500M LARGE SCALE GEO	1-5 GW PROTO
								LEO	GEO	LEO	GEO		
LEVEL 1													
CAPITAL INVESTMENTS	10												
TRANSPORTATION COST	10												
FRONT-END DDT&E	10												
RESOURCE LIMITS	10												
COMPETITIVE COST OF ENERGY	10												
PHASE CONTROL	2	5							7		8	10	10
LAUNCH RATES	10												
ANTENNA POINTING & CONTROL	5	6						7	7.5	8	8.5	9	10
SPACE CONSTRUCTION PROCESSES	2	3	4	4.7	5.5			6	6	8	8	9	10
INCIDENT MW RADIATION													
IONOSPHERIC HEATING	2	8										8.5	10
RFI	2	4	5.5	6				7	8	8.5	8	10	10
BIOLOGICAL	2	7										0	10
SCINTILLATION	2							4	5	4	7	10	10
LEVEL 2													
DC-RF CONVERTERS	2	4	5	6		7	7	6	6	6	9	10	10
HIGH VOLTAGE SPACE CHARGING	4	5	6	6		7	7	6.5	8.5	8.5	9.5	10	10
LIGHTWEIGHT BLANKET PRODUCIBILITY													
MASS	5.5	7.5	7.5	7.5		7.8		8	8	8.2	8.5	9.4	10
EFFICIENCY	5.5	6.5	6.7	6.8		7		7.5	8	8.2	8.8	9.6	10
COST	5	10											
PLASMA INTERACTIONS	4	5	6	6		7	7	8.5	8.5	6.5	9.5	10	10



manner, so that all parts were additive, it would imply that the issue could not be resolved if any element was dropped from or added to the scenario. By developing the data as indicated, elements could be dropped or added without restructuring the entire data base; yet, the contribution of any one element was readily available.

As summarized in Figure 1.4-2, the preliminary conclusion reached through this analysis is that there is a significant probability that about 85% of the identified critical technical issues can be substantially resolved through the definition and application of a comprehensive ground testing and Shuttle sortie verification program. With this conclusion in mind as an overview guideline, definitive development planning was undertaken.

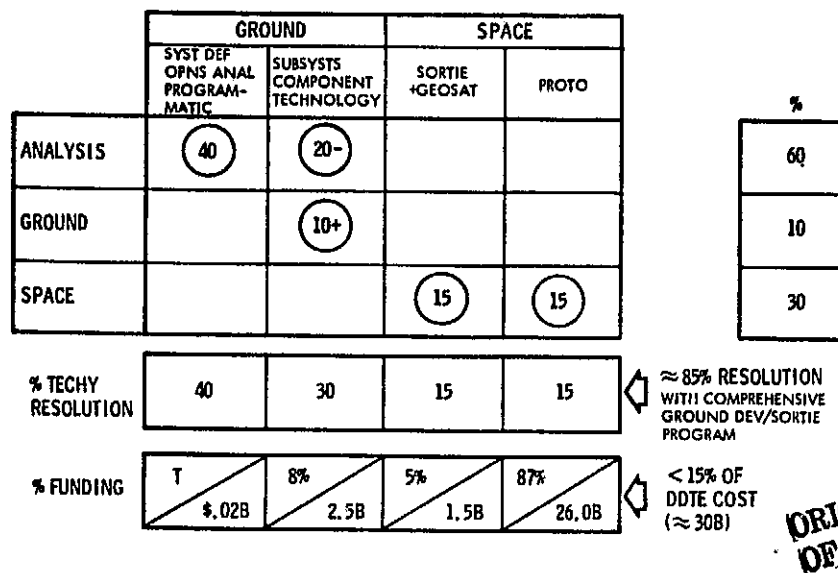


Figure 1.4-2. Resolution of Technical Issues



1.5 TECHNOLOGY DEVELOPMENT PLAN/SCENARIOS

1.5.1 PLANNING OBJECTIVES AND CONSIDERATIONS

In order to define SPS technical and programmatic options, an ERDA task group was established in 1976, to investigate previous work and recommend an evaluation program. The task group, with NASA support, concluded that insufficient information was then available for any significant program decisions, and recommended several program options with varying funding levels and technical and programmatic risk assumptions. The option finally selected for implementation, although providing a guideline permitting initiation of technology advancement/development in FY 1981, established that programmatic decisions would be considered a high risk approach since launch vehicle and orbital operational questions would not be resolved.

Based upon this background and key resolution evaluation and conclusions, technology planning requirements were defined to (1) satisfy the development planning objectives shown in Table 1.5-1, (2) provide significant resolution of critical technical issues, and (3) establish success-dependent commitment decision points that would permit the achievement of the 1995-2000 system IOC goal.

Table 1.5-1. Technology Verification Planning Objectives

<u>EVALUATE & STRUCTURE AN SPS TECHNOLOGY VERIFICATION/DEMONSTRATION PROGRAM BASED ON THESE REQUIREMENTS</u>
✓ MINIMIZE FRONT-END COSTS
✓ UTILIZE SHUTTLE CAPABILITY TO MAXIMUM
✓ MAXIMIZE GROUND TESTING
✓ REFLECT REASONABLE LEAD-TIMES
<u>EVOLVE DEVELOPMENT PLANNING REQUIREMENTS FOR THESE KEY INITIAL DEVELOPMENT PLAN ELEMENTS</u>
✓ GROUND DEVELOPMENT/ANALYSIS
✓ ORBITAL DEVELOPMENT/DEMONSTRATION
✓ MASS-TRANSFER CAPABILITY
<u>EVALUATE VERIFICATION TEST FACILITY CONCEPTS FOR RESOLVING THESE CRITICAL FRONT-END TECHNOLOGY ISSUES</u>
✓ IONOSPHERIC EFFECTS/RFI
✓ MAN'S PERFORMANCE IN SPACE - ORBITAL ASSEMBLY
✓ MPTS PHASE CONTROL FOR FEASIBILITY AND MICROWAVE TRANSMISSION EFFICIENCY

Development/verification planning analysis was directed toward the evolution of a planning scenario that met the stated objectives, was technically possible, economically attractive, and took into account constraining considerations such as (1) requirements for very large-scale end-to-end demonstration in a compressed time frame, (2) the relative cost/technical merits of ground testing versus space testing, and (3) the need for large mass flow capability to LEO and GEO at reasonable cost per pound.

The logic flow guiding the development planning analysis is shown in Figure 1.5-1.

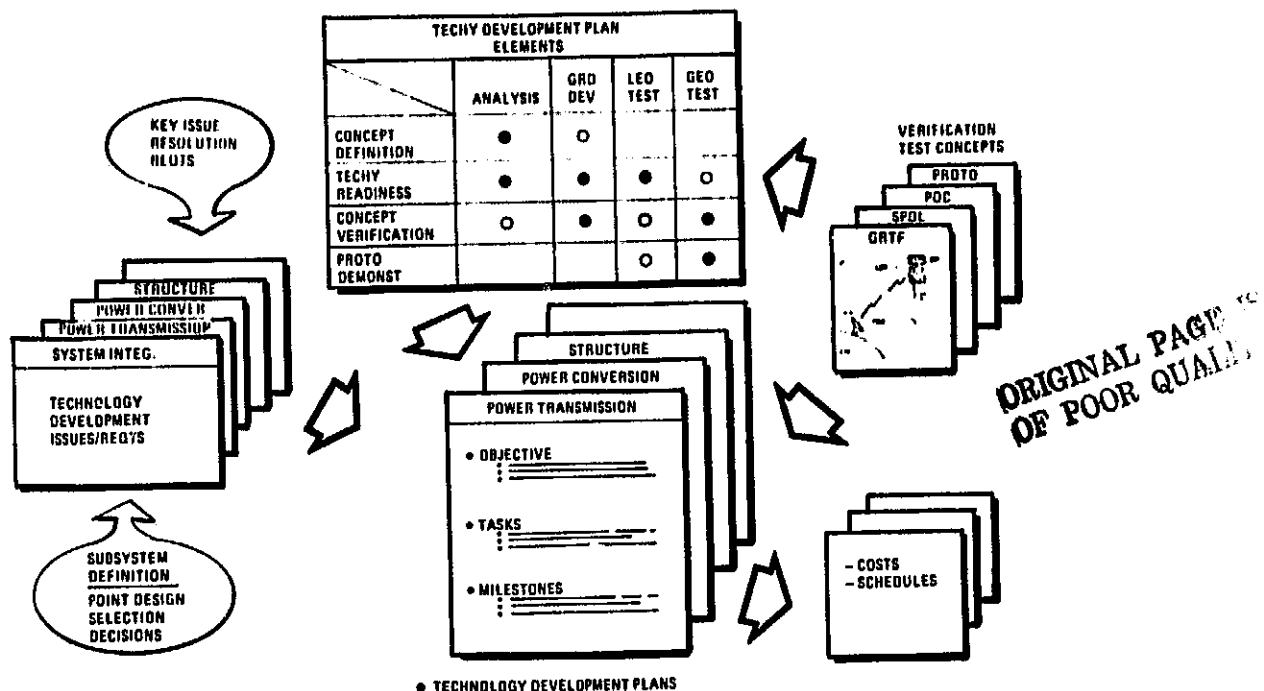


Figure 1.5-1. Technology Development Planning Logic Flow

1.5.2 DEVELOPMENT PLAN OPTIONS

Three planning scenarios were postulated to frame the full spectrum of cost/risk options; these are listed below:

- Guideline: National Goal, Deadline-Oriented Plan (IOC, 1995)
- Option A: Evolutionary Development Plan (IOC, 2005)
- Option B: All-Up Prototype Development Plan (IOC 1998)

Probably the most critical parameter influencing SPS technology development planning is the massive flow requirement to LEO and GEO as a function of development lead-time. The parameter is illustrated in Figure 1.5-2 for the three postulated development planning options.

Deadline-Oriented Plan

The deadline-oriented approach dictates mass flow rate increases per year/each year of up to 1.5 million pounds to geosynchronous orbit, and mandates a technical effort supported by a national goal and immediate commitment of heavy front-end DDT&E funding. Development lead-times for space verification test hardware are compressed beyond all projected experience and intolerably high-risk program decisions are mandated. The likelihood of a national commitment to SPS development in 1981 is minimal as reflected programmatically in the introduction recently in Congress of *House Concurrent Resolution 451* which

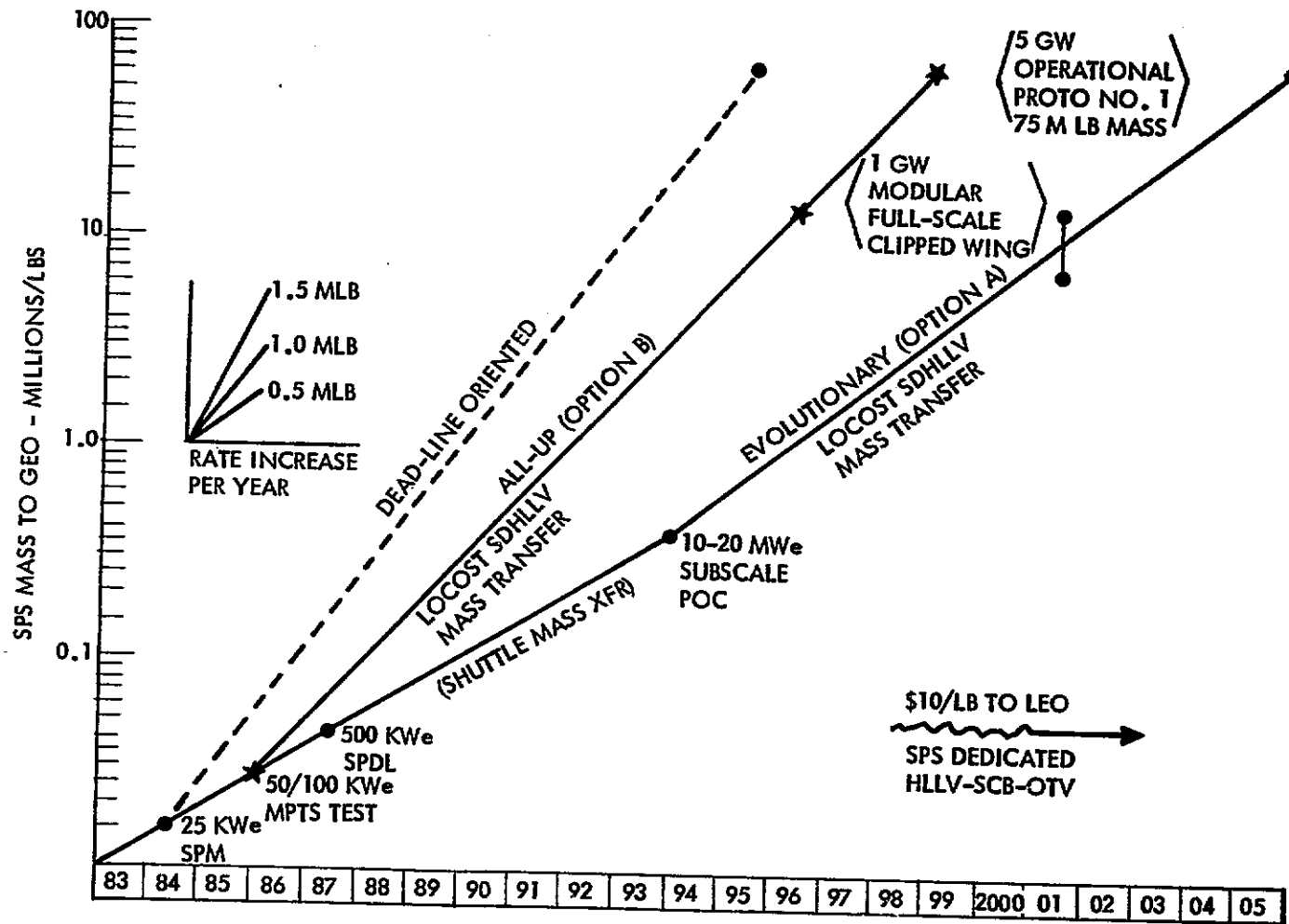


Figure 1.5-2. SPS Mass Flow to GEO - Buildup Rate



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states the crucial need to identify long-term national goals in space. Specifically the Resolution calls for the Office of Technology Assessment to:

Organize and manage a thorough study to determine the feasibility, potential consequences, advantages and disadvantages of developing as a National Goal for the year 2000 the first manned structures in Space for the conversion of solar energy and other extraterrestrial resources to the peaceable and practical use of human beings everywhere.

Option A - Evolutionary Development Plan

The evolutionary development approach implies an ordered step-by-step hardware capability increase, with each funding commitment decision supported by a demonstrated verification process. A representative scenario of Option A technology development plan elements is shown in Figure 1.5-3. The evolutionary development option is characterized by extensive use of increasingly complex orbital test articles for sequential verification demonstration, each test article with its own significant lead-time requirements, which lead ultimately to a much extended system IOC date as late as CY 2005, as well as very high front-end development costs.

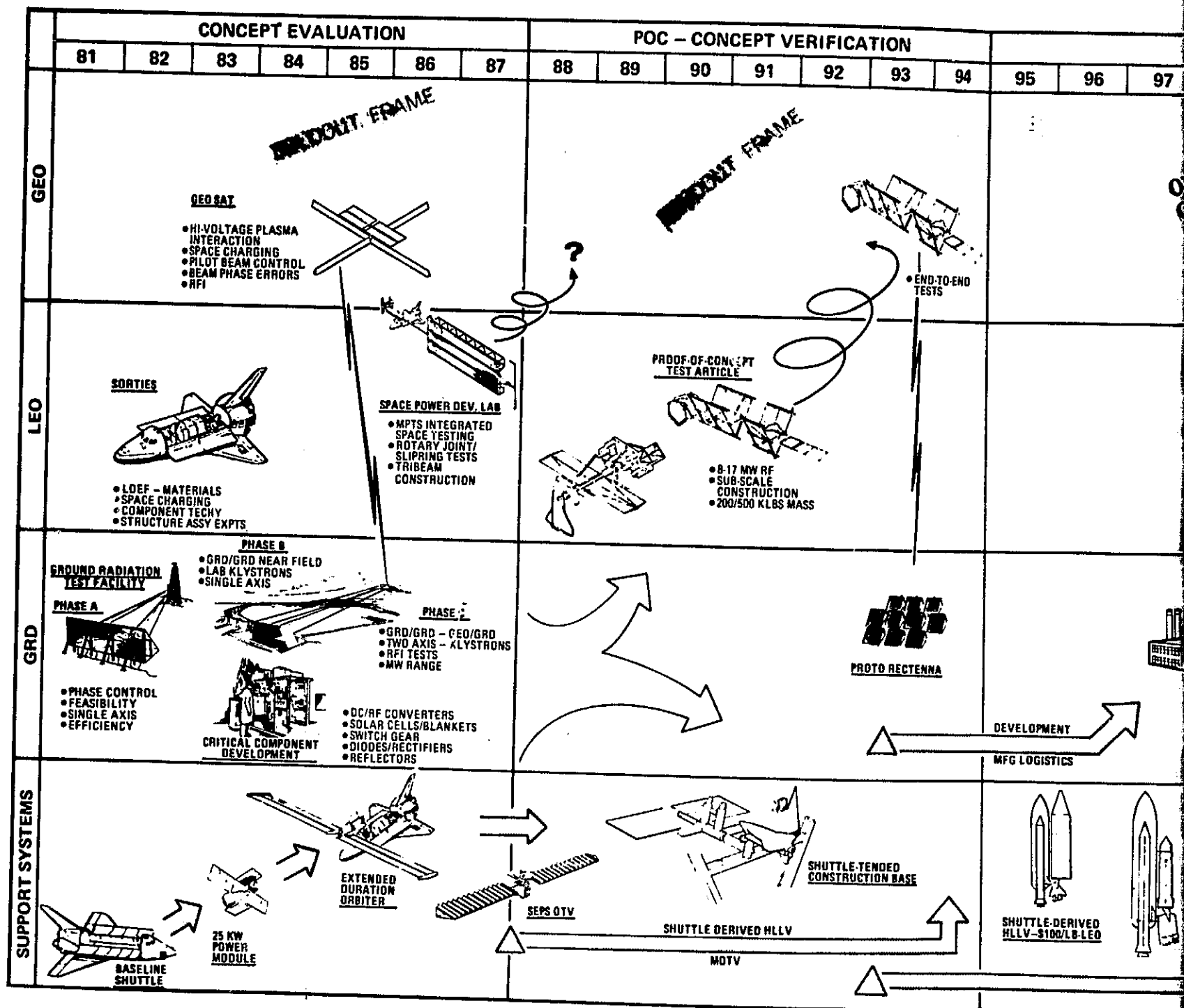
Option B - All-Up Prototype Development Plan

This scenario has evolved as an optimized, technically possible alternative plan with reasonable cost/risk factors. The plan concentrates on early technology advancement based upon a balanced program of ground test and Shuttle utilization, and has been selected as the baseline scenario for the SPS verification plan. The SPS development plan elements of Option B are illustrated in Figure 1.5-4.

1.5.3 TECHNOLOGY PLAN BASELINE - OPTION B

This SPS development plan scenario is characterized by a concentrated ground test and Shuttle sortie program for the verification test phase, followed by an all-up/full-scale clipped-wing prototype demonstration during the system development phase. Key commitment decisions are listed below.

1981	Initiation of technology verification effort leading to technology readiness in 1987. Commitment to development of Shuttle-derived, low-cost HLLV-OTV development
1987	Initiation of full system development prototype construction phase. Commitment to development of SPS-dedicated transportation and construction support system elements



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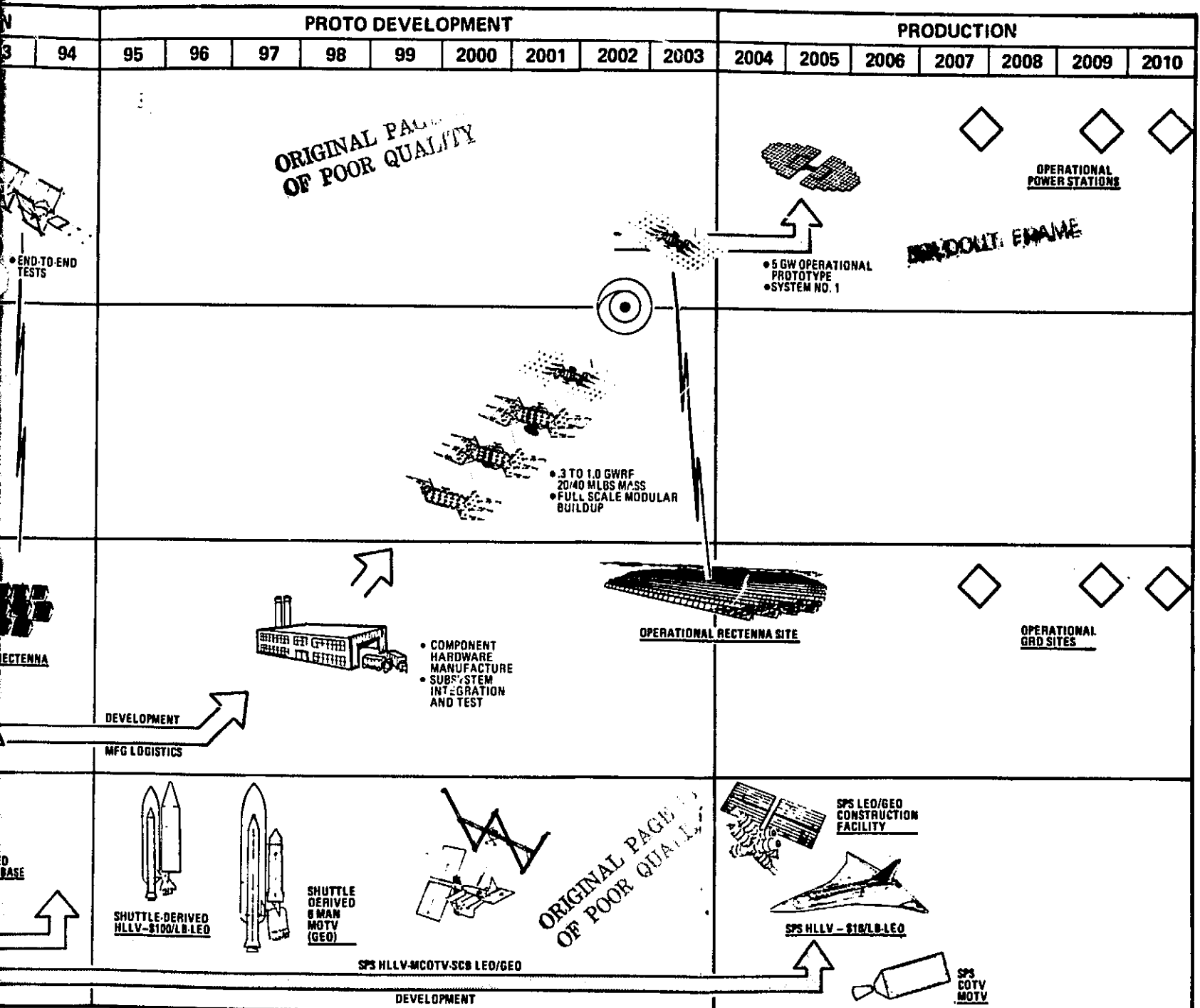
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Figure 1.5-3. Option A Technology Develop



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Option A Technology Development Plan Elements

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SPS ALL-UP PROTO DEVELOPMENT PLAN ELE

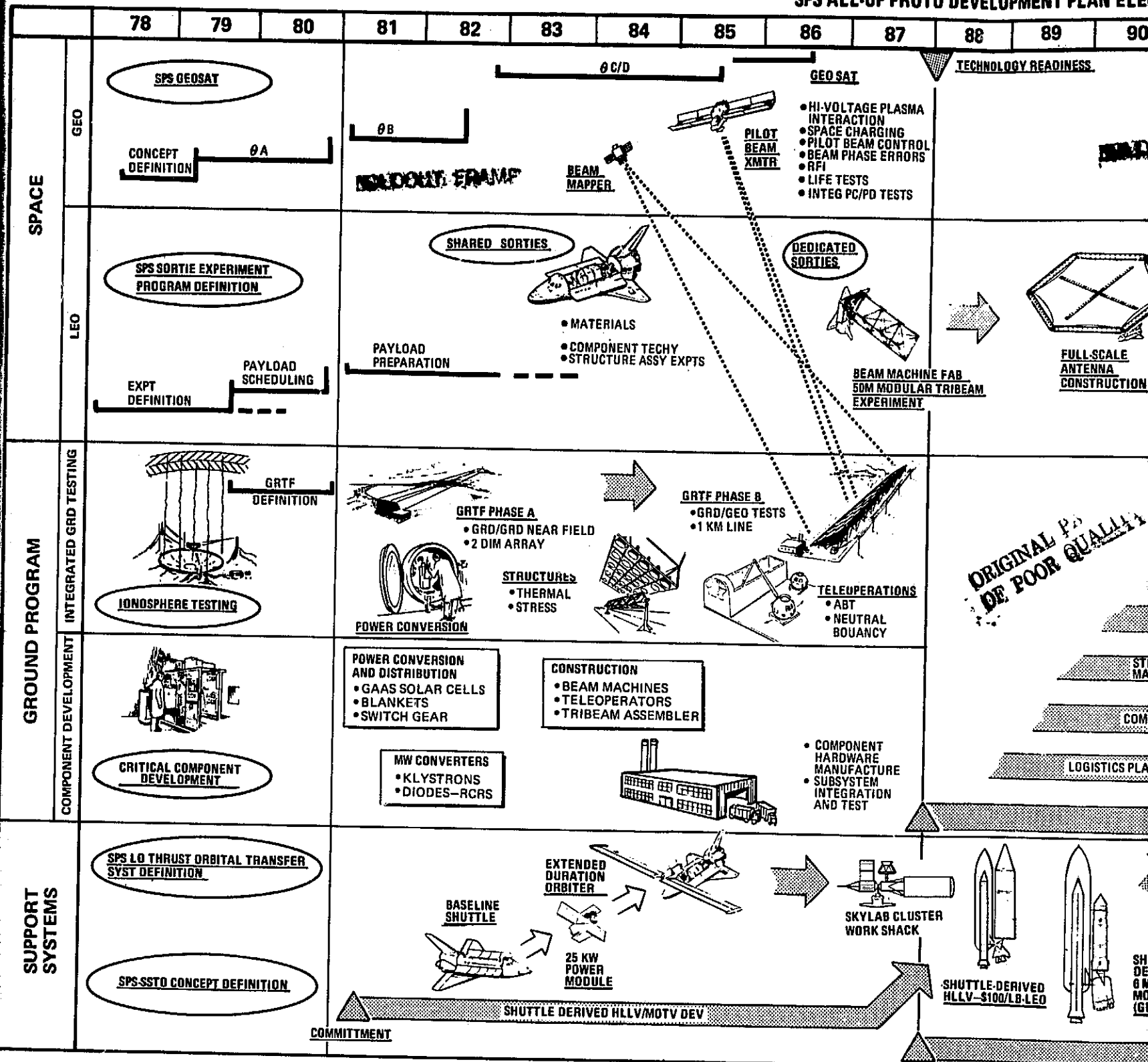


Figure 1.5-4. SPS All-Up Prototype Development Plan

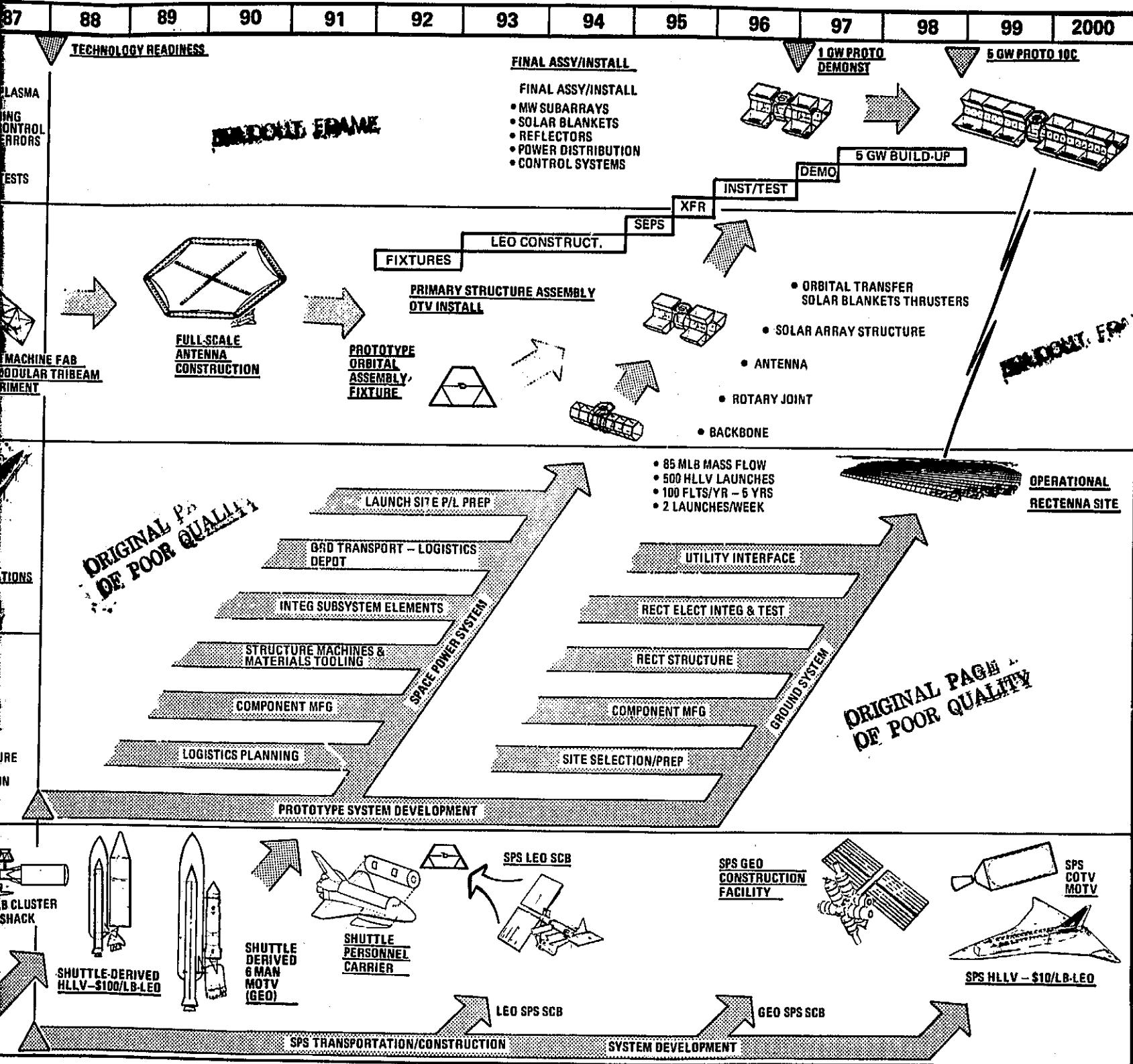
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PROTO DEVELOPMENT PLAN ELEMENTS - OPTION B



Prototype Development Plan Elements - Option B

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Key development test elements in the verification phase (1981-1987) include:

- Ground radiation test facility for ground-to-ground near-field MPTS tests and ground-to-geosynch testing for far-field phase control and beam quality tests.
- SPS GEOSAT test system consisting of the following test subsystems: pilot-beam transmitter, beam-mapping subsatellite, MPTS component test module, modular GaAs/CR-2 solar arrays, and prototype EOTV power conditioner/thruster system.
- Orbital assembly dedicated sorties to build 50-m tri-beam elements and assemble full-scale microwave antenna structure.

The development plan is structured in three time phases:

- | | |
|---|-----------|
| • Early experimental research program | 1979-1980 |
| • Technology verification (leading to technology readiness in 1987) | 1981-1987 |
| • Prototype system development (leading to 1-GW prototype demonstration in 1996, and 5-GW system IOC in 1998) | 1988-1998 |

The early experimentation and technology verification program phases (1979 to 1987) are described in further detail in Section 2.0.

Prototype Development/Demonstration

The prototype development phase is initiated with demonstration of technology readiness in 1987, and culminates in a full-scale 1-GW prototype demonstration in 1996. The prototype demonstration system will be assembled in LEO using Shuttle derivative extended-duration cargo transfer and orbital construction/habitation support elements. Shuttle sortie tri-beam construction and assembly demonstrations will be extended to construction of tri-beam assembly complexes (Figure 1.5-5), and further buildup into the prototype master assembly fixture as visualized in Figure 1.5-6. The assembly fixture will then be used to construct the clipped-wing prototype, and will be transferred along with the demonstration vehicle to geosynchronous orbit where it will be used to "grow" the 1-GW prototype system to a full-size 5-GW system by the end of 1998.

The 1-GW prototype system will utilize its own solar panels along with an integrated solar electric propulsion system to propel itself to GEO. While the prototype/early operational SPS will be self-propelled from LEO to GEO, subsequent production systems will be assembled in GEO utilizing a dedicated EOTV for mass transfer from LEO.

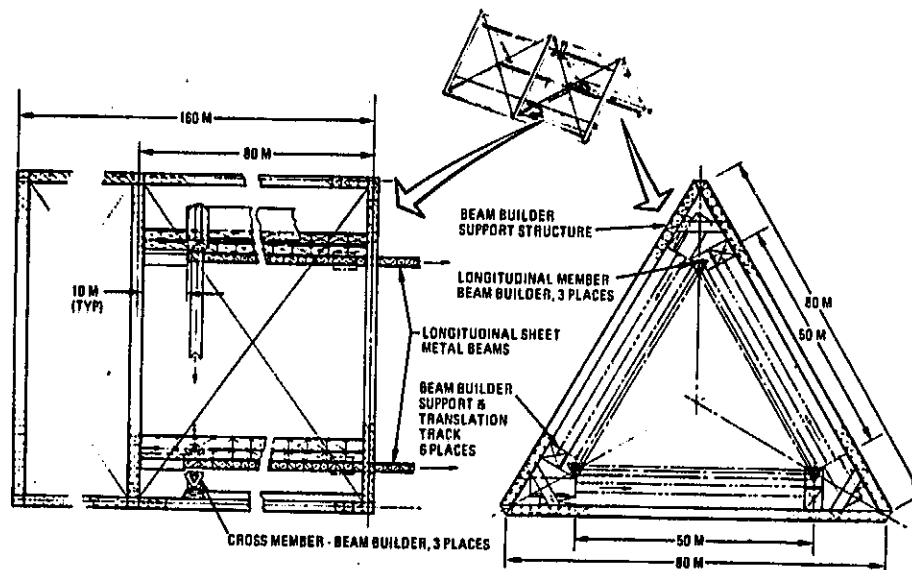
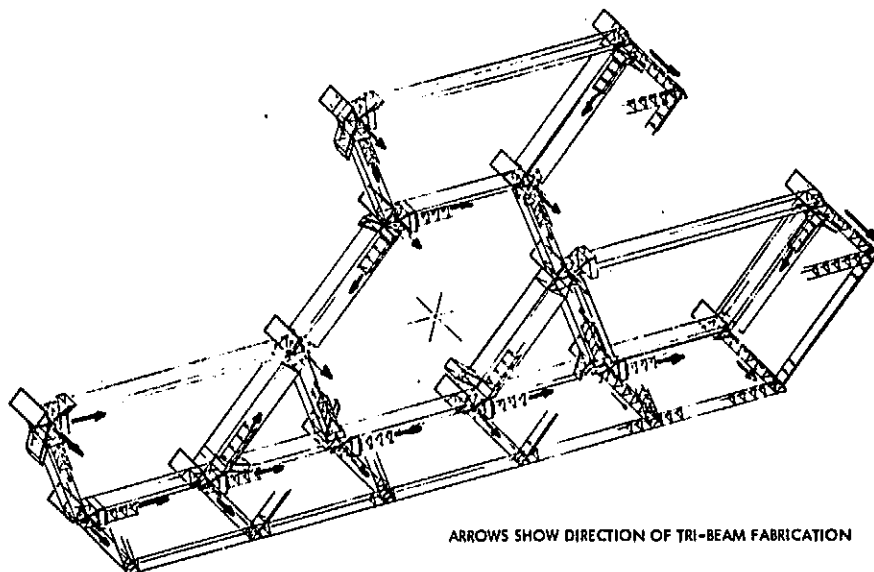


Figure 1.5-5. Tri-Beam Complex



ARROWS SHOW DIRECTION OF TRI-BEAM FABRICATION

Figure 1.5-6. Satellite Tri-Beam Construction Perspective

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2.0 TECHNOLOGY EXPERIMENTAL/VERIFICATION PROGRAM (1979-1987)

The experimental/verification program leads to technology readiness in 1987 in support of a prototype development commitment at that time. A two-phase program is proposed as outlined below.

- Early Experimental Research (1979-1980) - The early experimentation phase of the baseline SPS verification/development plan covers the 1979-1980 time frame, and includes those exploratory technology experimental elements categorized as mandatory tests prerequisite to a logical commitment decision to proceed with technology verification/advancement activities in 1981.
- Technology Verification Phase (1981-1987) - This is the basic all-out development effort involving a comprehensive ground test program for component development and integrated subsystem testing, supported by Shuttle sortie testing and multi-function geosynchronous satellite experiments.

2.1 VERIFICATION PROGRAM ELEMENTS/LOGIC

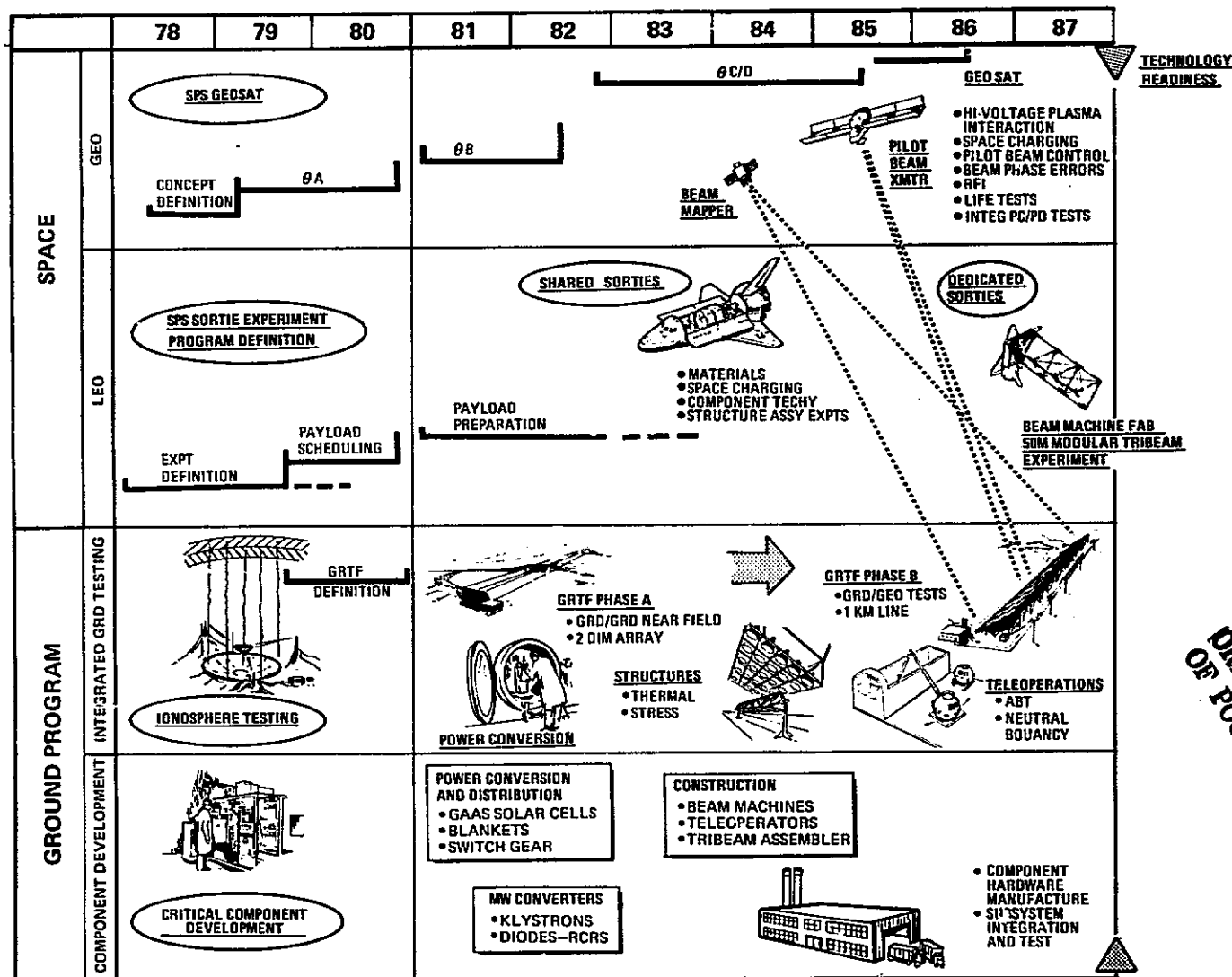
Technology verification planning was structured by subsystem area to include all of the front-end planning elements shown in Figure 2.1-1. The planning process derived sequential test elements, summarized typically in Tables 2.1-1 and 2.1-2. While preliminary in nature at this point in the system design, these test elements nonetheless categorize the type of testing activity and facilitization embodied in the Option B technology verification plan.

Those critical technical areas judged to be "technically testable" and responsive to methodological analysis were selected from the overall key issue summary, and categorized by major SPS subsystem area to provide key technical resolution requirements based on subsystem verification test planning. Table 2.1-3 summarizes the key issue/subsystem matrix.

Subsequent development test plans for each major subsystem were structured to provide substantial resolution of these critical technical requirements.

The GEOSAT multi-test element system includes test experimentation for several major subsystems and is treated as a separate geosynchronous system test element. This section, therefore, consists of the following verification program subsections.

- Microwave Transmission
- Power Conversion
- Power Distribution
- Structures and Assembly
- GEOSAT Definition and Integration
- STS Propulsion Technology



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Figure 2.1-1. SPS Technology Advancement Plan Elements

Table 2.1-1. Technology Verification Test Elements (Ground)

EARLY ANALYSIS EXPLOR. LAB DEVELOPMENT	GROUND TEST PROGRAM	
	COMPONENT DEVELOPMENT	INTEGRATED TEST
1978-1980	1981-1985	1982-1987
• COMPUTER MODELING PHASE CONTROL • LABORATORY BREADBOARDS • ARECIBO HEATING FACILITY TESTS • CONVERTER LAB ANALYSIS & TEST • HIGH-VOLTAGE POWER DISTRIBUTION LAB TESTS • GaAs CELL EFFICIENCY LAB TESTS • SPS GEOSAT CONCEPT DEFINITION • GRTF CONCEPT DEFINITION • SORTIE EXPERIMENT DEFINITION • ROCKWELL-FWTO CONCEPT FEASIBILITY STUDIES • EOTV ANALYSIS & COMPONENT LABORATORY TESTING	• COMPONENT LAB MODELS • COMPONENT PILOT LINE PRODUCTION • ENVIR. LAB TEST FACILITIES • MATERIALS RECOVERY PILOT LINE (GALLIUM) • LARGE (~100 CM) ELECTRIC THRUSTER DEVELOPMENT WITH ARGON PROPELLANTS • EOTV BREADBOARD TESTING • CHEMICAL OTV MONITORING/SELF-TESTING COMPUTER EQUIPMENT • TURBOFAN-RAMJET ENGINE COMPONENT DEVELOPMENT • ROCKWELL-FWTO WING/TANK STRUCTURAL FAB & TESTS	• MICROWAVE GROUND/GROUND RANGE • MPTS/GEOSAT GROUND/GEO RANGE • STRUCT. SIMILITUDE TEST FACILITY • LARGE STRUCTURE ASSY SIMULATION FACILITY • SOLAR BLANKET PILOT LINE • POWER CONVERSION DISTRIBUTION INTEGRATION SUB-SYSTEM LAB • THERMAL-VACUUM CHAMBER TESTS OF EOTV PROTOTYPE • CHEMICAL OTV PROPULSION SYSTEM TEST • ROCKWELL-FWTO WIND TUNNEL MODEL TESTING • INTEGRATED TURBOFAN-RAMJET TESTING (MODIFIED J-58)



Table 2.1-2. Technology Verification Test Elements (Space)

SPS GEOSAT	LEO - SHUTTLE UTILIZATION	
	SHARED SORTIE	DEDICATED SORTIE
	1982-1985	1986-1988
1986-1987 • PILOT BEAM TRANSMITTING MODULE • BEAM MAPPER SUBSATELLITE • MODULAR GaAs SOLAR ARRAY ELEMENTS - REFLECTORS • EOTV PROPULSION MODULE • POWER DISTRIBUTION - SLIP RING SUBSYSTEM • MPTS COMPONENT TEST MODULE	1982-1985 • STRUCTURAL MATERIALS LIFE TESTING EXPERIMENTS • HIGH-VOLTAGE PLASMA EFFECTS - ARCING - RFI • BEAM MACHINE SUITCASE EXPERIMENTS • STRUCT. ASSY - JOINTS - TECHNIQUES - TOOLS • EOTV PROPULSION MODULE PROTOTYPE TEST	1986-1988 • GEOSAT ORBITAL INJECTION • LARGE STRUCTURE ORBITAL ASSY DEMO - 50-M TRI-BEAM • FULL-SCALE MPTS ANTENNA CONSTRUCTION DEMO • SUBORBITAL HYPERVELOCITY TEST ARTICLE OF ROCKWELL-FWTO

Table 2.1-3. Critical Technical Issues by Major Subsystem

LEVEL	MPTS	POWER CONVERSION	POWER DISTRIBUTION	STRUCTURE ASSY/CONST	TRANSPORTATION
I	* PHASE CONTROL * ANTENNA POINTING AND CONTROL * INCIDENT MICROWAVE RADIATION			*SPACE CONSTRUCTION PROCESSES	* TRANSPORTATION COST TO ORBIT * FRONT END DDT&E * LAUNCH RATES
II	• MICROWAVE ELEMENT LIFE/FAILURE RATES • DC/DC EFFICIENCY • DC/RF CONVERTERS • WAVEGUIDES/RCRS • SHUTDOWN/STARTUP • MICROWAVE BEAM DISPERSION ANALYSIS	• LIGHT-WT BLANKET PRODUCIBILITY • POWER CONVERSION DEVICES LIFE/DEGRAD • DC/DC EFFICIENCY • REFLECTOR FILM DEVELOPMENT • REFLECTOR FILM FLATNESS CONTROL	• DC/DC EFFICIENCY • ROTARY JOINT POWER TRANSFER • POWER SWITCHING • VOLTAGE/CURRENT REGULATION • HIGH VOLTAGE SPACE CHARGING • PLASMA INTERACTIONS	• MAN-MACHINE PRODUCTIVITY • SAT. POINTING & CONTROL • ASSEMBLY RATES	• OTV PERFORMANCE • ELECTRIC THRUSTER PERFORMANCE • LEO/GEO TRANSFER OF LARGE STRUCTURE
III	• RECTENNA ELEMENT LIFE/FAILURE RATES • MW BEAM ON-ORBIT MAINTENANCE HAZARDS	• REFLECTOR FILMS DEGRADATION	• POWER CONDUCTION • RECTENNA POWER DISTRIBUTION & CONTROL	• CREW SAFETY • PRODUCTIVITY • EVA REQTS	



2.2 MICROWAVE POWER TRANSMISSION SYSTEM

The microwave power transmission system (MPTS) is clearly the most critical SPS subsystem from the standpoint of technology development and subsystem feasibility. State-of-the-art advances are required in dc/RF and RF/dc conversion, phase control, RFI suppression, and thermal control. MPTS test concepts are required which are technically manageable, economically acceptable, and capable of demonstrating substantial resolution of the key technical issues postulated for this major subsystem.

A comprehensive component development and ground test program is proposed culminating in full-scale line array ground to geosynchronous power beam testing, along with GEOSAT environmental testing of component elements and combinations. The proposed MPTS development test flow sequence is shown in Figure 2.2-1. Key to the proposed development sequence is the progressive test buildup of modular elements of the MPTS subsystem including the rectenna. Preliminary point design microwave antenna modular element sizes are shown in Figure 2.2-2. The largest standard element is the 30-m $\times$ 30-m mechanical module which mates with the major antenna support structure. The mechanical module is comprised of 10-m $\times$ 10-m subarrays, each of which has a single set of its retro-electronic circuits. Each subarray is comprised of individual power modules, each fed by a single 50 MW converter unit.

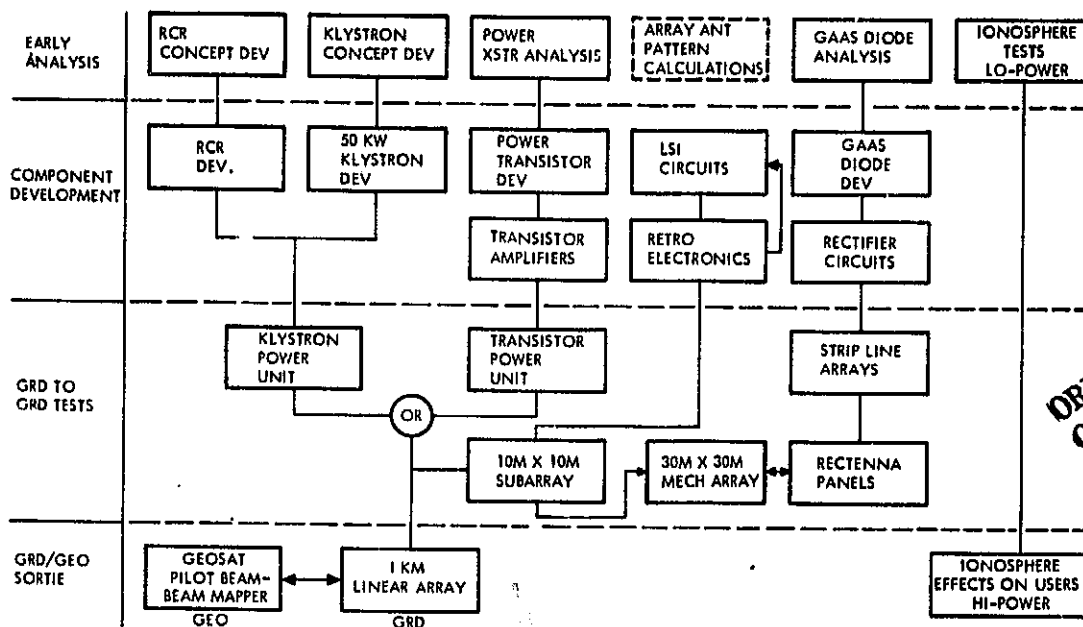


Figure 2.2-1. MPTS Development Test Flow Sequence

2.2.1 SUPPORTING RESEARCH AND TECHNOLOGY (SRT)—EARLY ANALYSIS/EXPERIMENTAL RESEARCH

Ionosphere/microwave beam interaction effects constitute a primary Level I key technology issue and require a mandatory early experimentation program to test for non-linear effects at 2.5 GHz using the Arecibo facility. The test

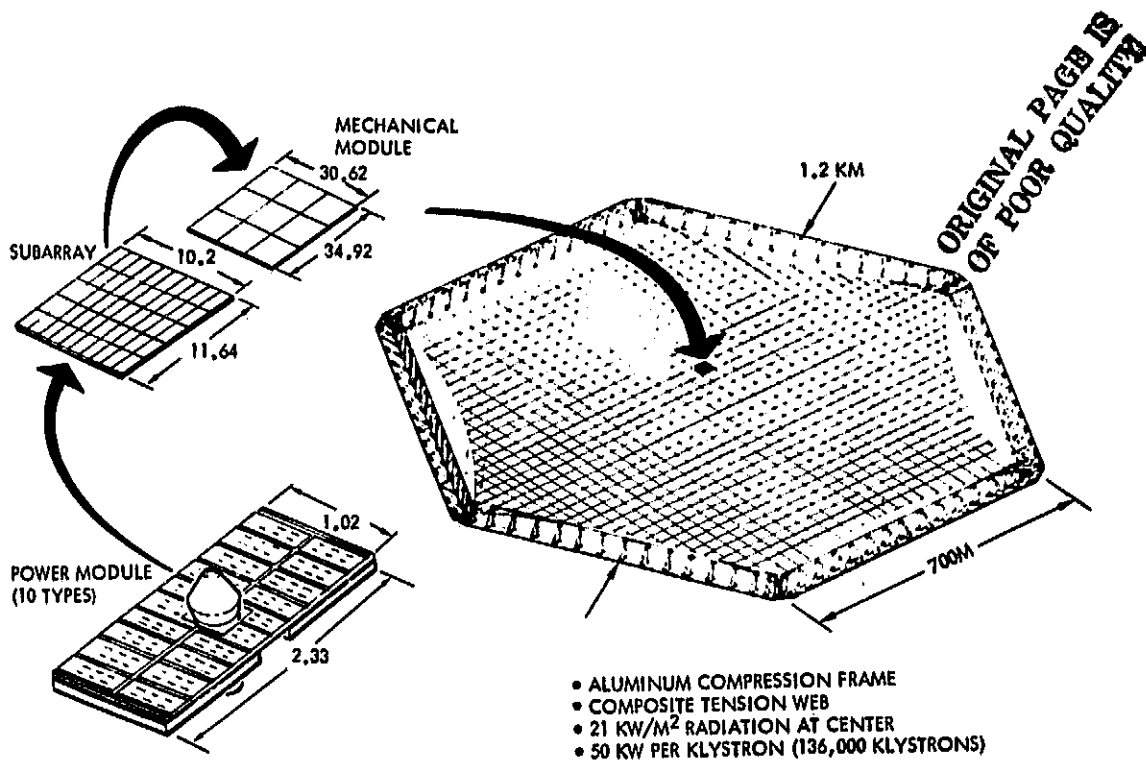


Figure 2.2-2. Microwave Transmission System - Satellite Antenna

program proposed by L. M. Duncan and W. E. Gordon of Rice University is recommended for implementation. This experimental program is outlined in detail in the Ionosphere/Microwave Beam Interaction study final report, dated September, 1977 (Contract NAS9-15212).

A key element of the MPTS development plan is the multi-phase Ground Radiation Test Facility which will require more in-depth early analysis concept definition and test logic development prior to 1981, to provide a detailed test verification framework for ground test and ground-to-GEO test activities.

Other early analysis and exploratory technology areas include:

- Resonant cavity resonator development
- 50-kW Klystron development
- Power transistor analysis
- Array antenna pattern calculations
- GaAs diode analysis

The criticality of these MPTS component elements relative to subsystem feasibility and efficiency requires early analytical exploratory computer modeling, simulation, and feasibility laboratory examination. Task descriptions, objectives, and approaches for these early analysis efforts are summarized in detail in Section 3.0 (Supporting Research and Technology Summary).



2.2.2 GROUND TEST PROGRAM

The MPTS development schedule is shown in Figure 2.2-3. The sequence of effort after early concept analysis and feasibility testing proceeds through development of component elements and modular element laboratory and environmental tests to progressively larger subarray sections, which come together in the ground radiation test facility for integrated subsystem testing.

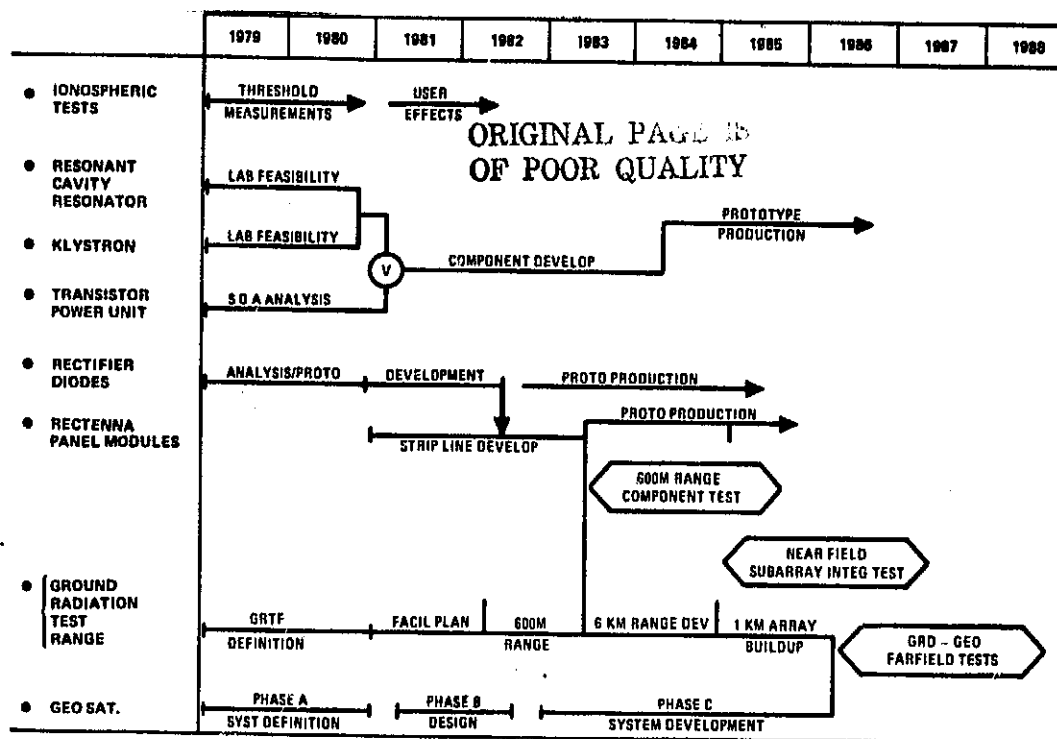


Figure 2.2-3. MPTS Development Schedule

Parallel component development of the Klystron/RCR module and solid-state power amplifier should be initiated with a final point-design power amplifier decision made prior to the 1981 technology verification program start date.

Prototype component development testing of transmitter and rectenna elements will take place initially in development laboratories and ultimately on the proposed field test range.

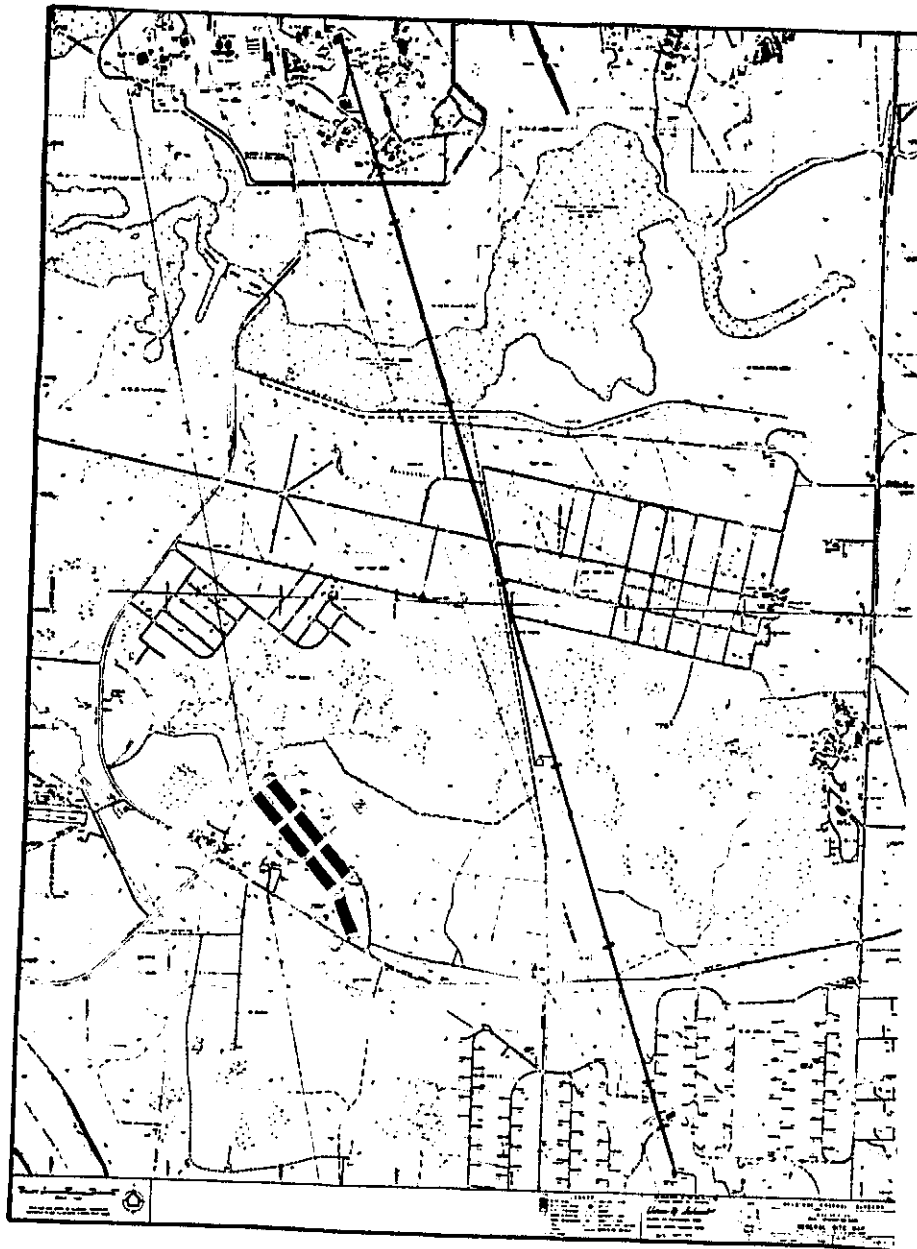
2.2.3 GROUND RADIATION TEST FACILITY

Extensive proof-of-subsystem-feasibility under controlled conditions is a primary requirement of MPTS development before high-cost, large-scale space environmental test evaluations can be planned. This effort can be performed in the proposed low-cost microwave test range facility, which provides three sequential range extension capabilities for near-field and far-field microwave testing. The range will be designed for testing of point-design modular microwave antenna and rectenna elements in progressive combinations of modules and subarrays.



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An integrated MPTS ground radiation test facility is hypothesized utilizing the MSFC propulsion and dynamic test area located in the southeast area of the Center facility, as shown in Figure 2.2-4.



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Figure 2.2-4. Integrated MPTS Ground Radiation Test Facility

A ground-to-ground integral range, with test capability of 600 m and 6 km, is pictorialized in Figure 2.2-5 using the Saturn dynamic test stands as range towers. The 6-km range is visualized as a 30-m 30-m microwave antenna module mounted on the large dynamic test stand, radiating to a complex of rectenna modules installed on a north-facing bluff at Contraves Station, S.S.E. of MSFC Center and located within the boundary of Redstone Arsenal serviced by secondary roads, but in an isolated, controlled area.

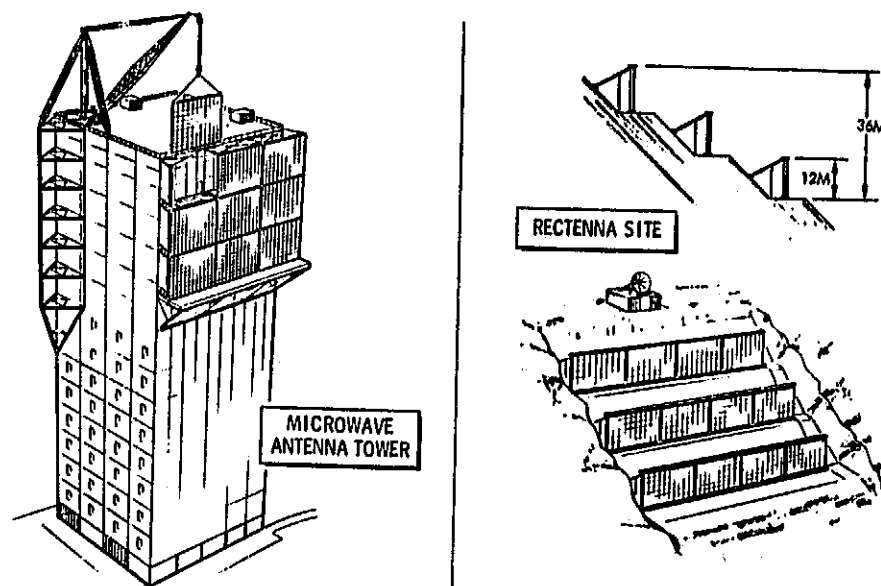


Figure 2.2-5. Ground-to-Ground Near-Field
Microwave Test Range

Phase A ground-to-ground near-field testing will utilize the 600-m range for unit power module tests initially, with progressive buildup of power module elements into the modular 10-m subarray. The proposed 600-m test range is shown in Figure 2.2-6. Larger-scale antenna testing with integrated retro-directive control circuitry will range from 10-m subarrays to full 30-m² antenna mechanical modules, utilizing the 6-km test range pictorialized in Figure 2.2-7. The proposed rectenna site for the 6-km range is shown in Figure 2.2-8. The 6-km range elevation profile is shown in Figure 2.2-9.

2.2.4 SPACE TEST PROGRAM

The principal space activity associated with MPTS technology development involves inverted far-field microwave transmission tests from ground to geosynchronous, utilizing a multi-test satellite far-beam mapping and pilot-beam retrodirective testing along with selective subsystem element environmental testing and RFI evaluation.

Phase B, Ground-to-GEO Test Elements. A 1-km linear transmitting antenna, one power module in width, is proposed for full-scale phase control testing as shown in Figure 2.2-10. Full-scale aperture testing is required to verify phase control linearity and array performance prior to commitment of major space antenna construction effort. The 1-km array measurement geometry is shown in Figure 2.2-11. Range to the edge of the near-field is calculated as:

$$R = 2 \frac{D^2}{\lambda} = 20,000 \text{ km.}$$

Obviously, no terrestrial range can satisfy this requirement, making the ground-to-geosynchronous test concept a viable cost-effective alternative to early full-scale space testing.



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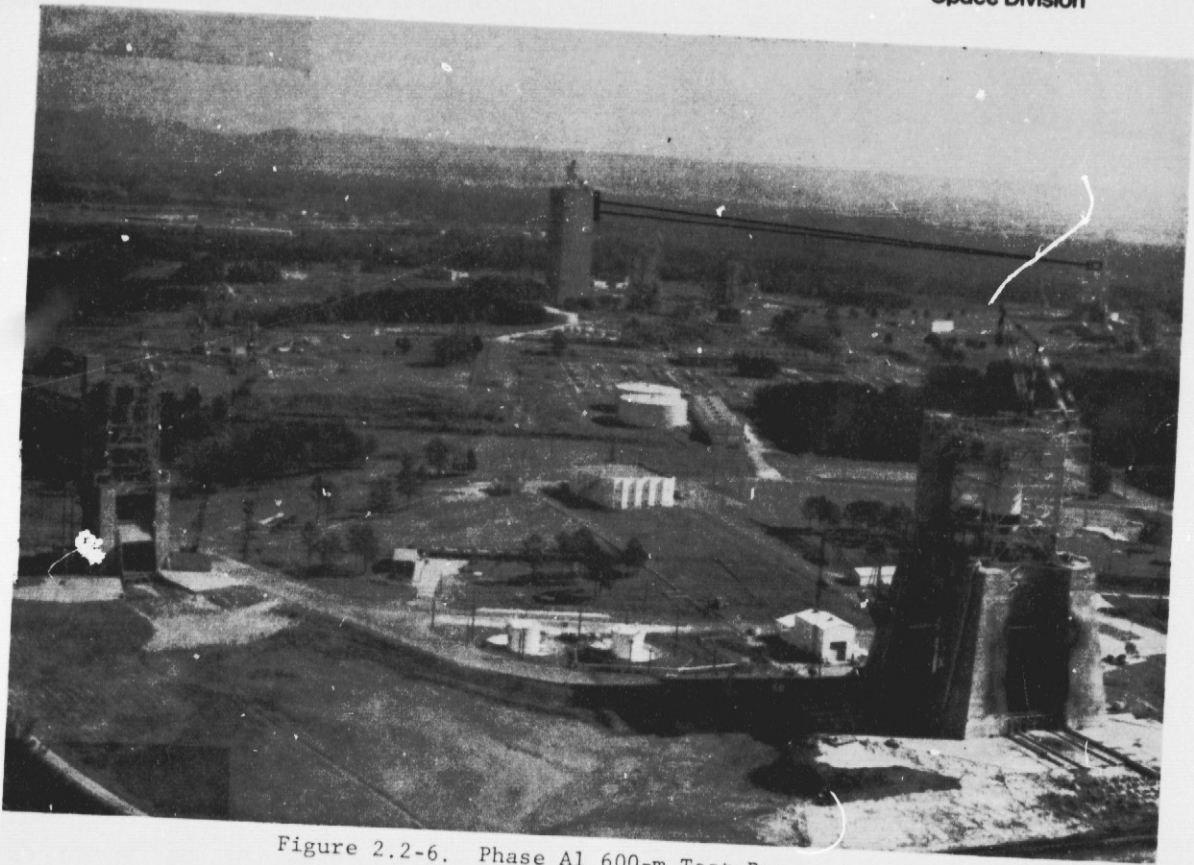


Figure 2.2-6. Phase A1 600-m Test Range

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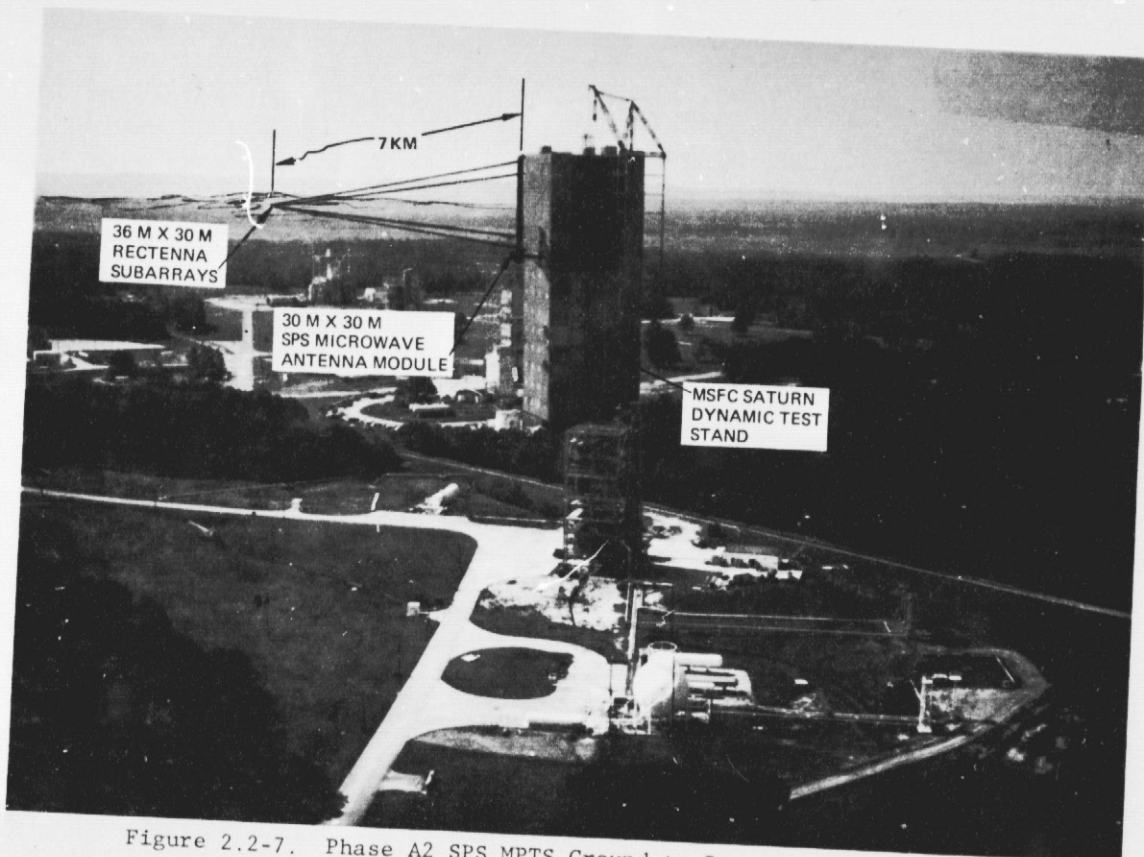


Figure 2.2-7. Phase A2 SPS MPTS Ground-to-Ground Test Concept,
Near-Field

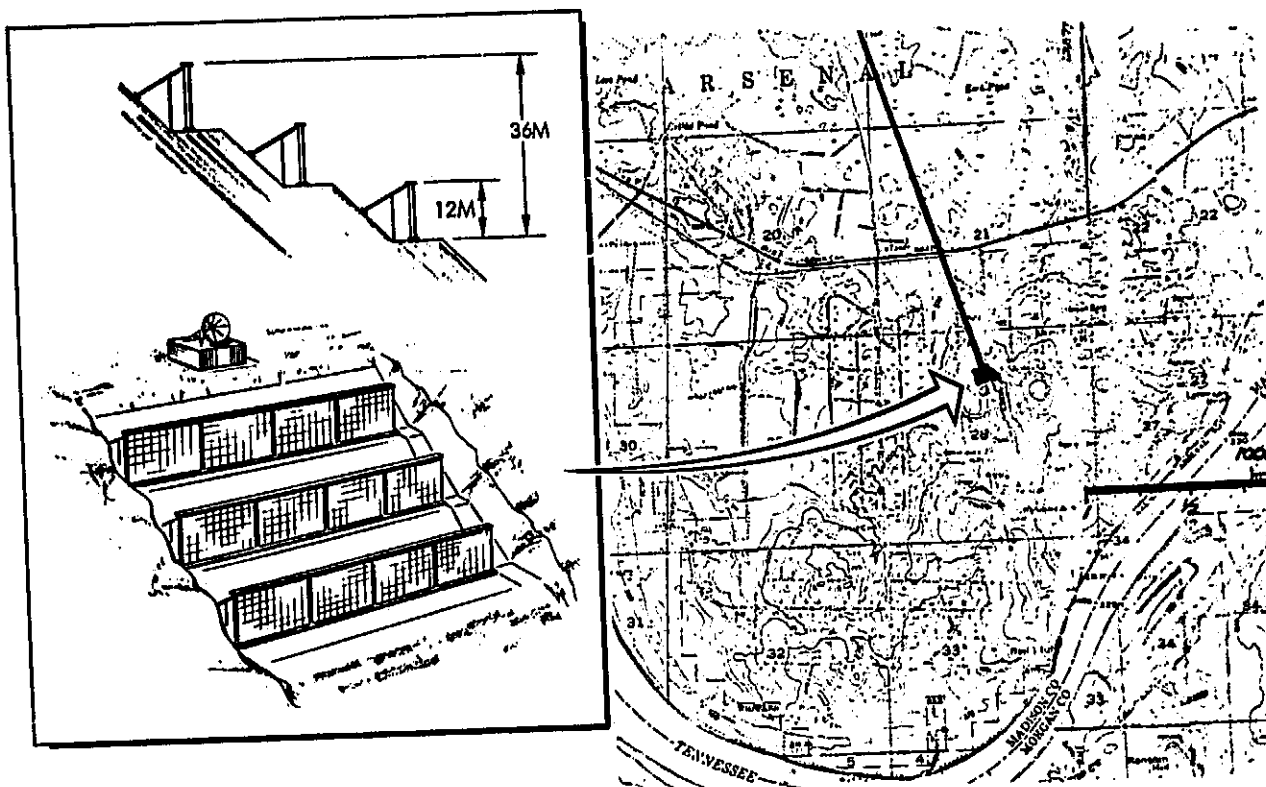


Figure 2.2-8. Rectenna Site

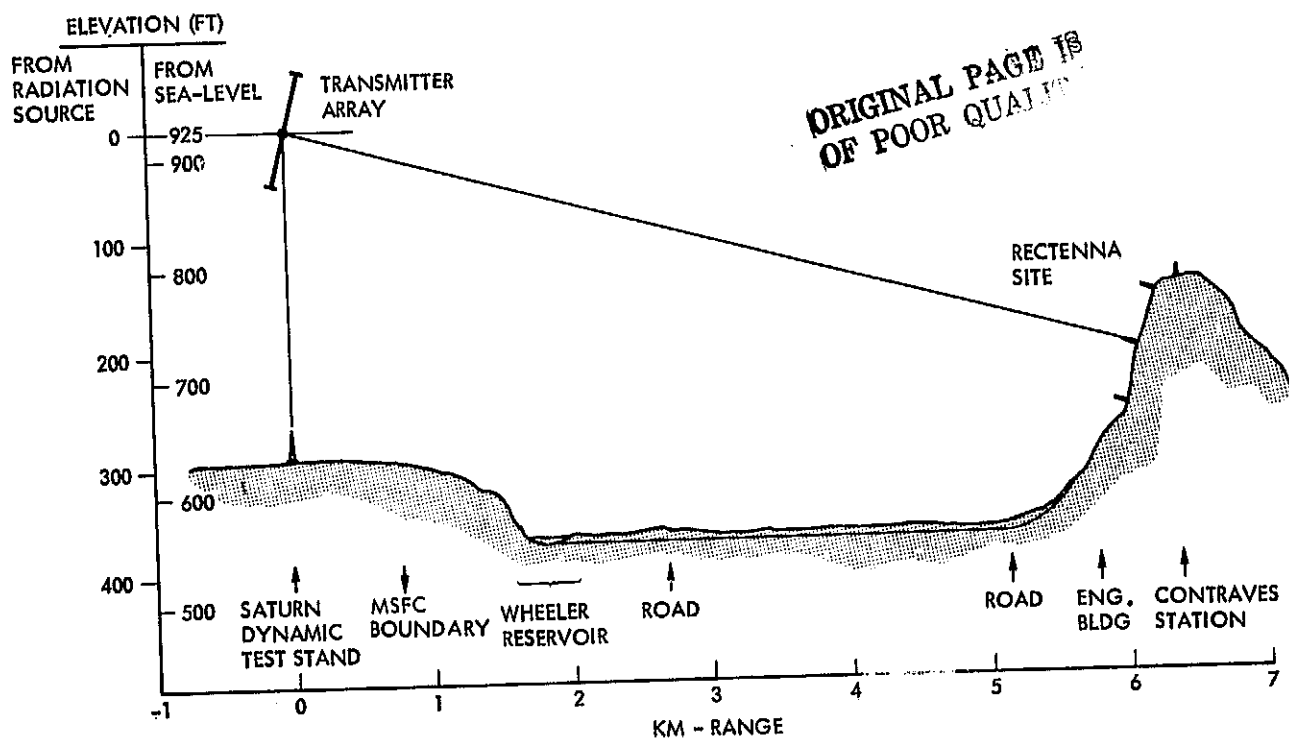
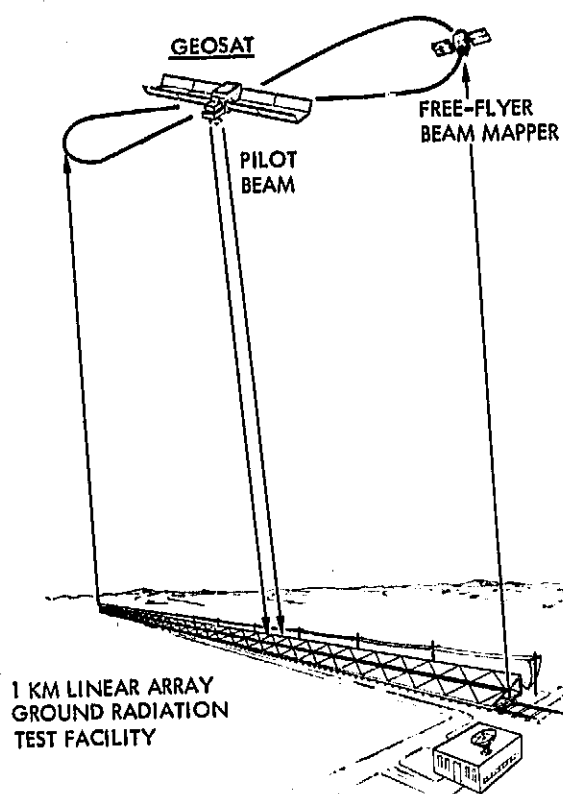


Figure 2.2-9. MPTS Ground Test Range Elevation Profile



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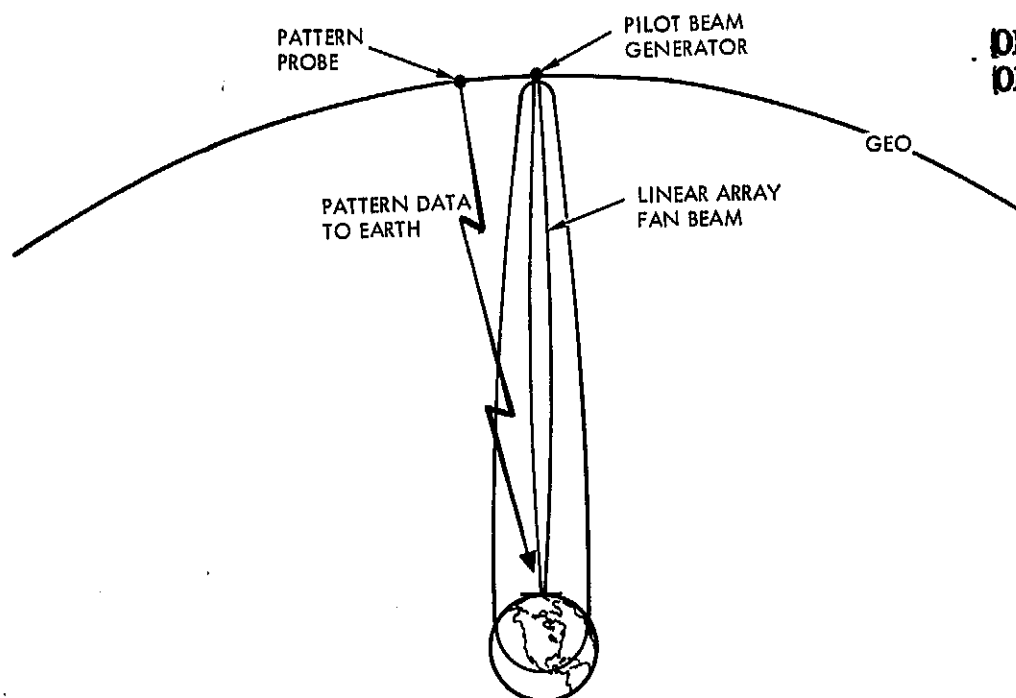
OBJECTIVES

- TEST PERFORMANCE OF RETROELECTRONICS USING FINAL APERTURE
- DETERMINE MANUFACTURING TOLERANCES FOR RETROELECTRONICS
- DETERMINE ATMOSPHERE EFFECTS
- TEST EFFECT OF TRANSIENTS
- POWER DENSITY PROFILE MEASUREMENTS

GRTF CHARACTERISTICS

- GROUND ANTENNA INSTALLATION
 - ✓ 1 KM EAST-WEST LINE SOURCE SIZE
 - ✓ ONE PWR MODULE WIDE - RADIATES 50 KW
 - ✓ LOCATION - S.E. USA
 - ✓ PROTO MODULAR MPTS ELEMENTS/PHASE CONTROL
- GEOSAT
 - ✓ INTEGRATED GEOSYNC ORBITAL TEST SYSTEM
 - ✓ GEOSAT ELEMENTS
 - PROTO 500 W PILOT BEAM
 - BEAM MAPPER SUB-SATELLITE
 - MODULAR GaAs SOLAR ARRAYS - 100 KW
 - SCALED POWER CONVERSION - POWER
 - DISTRIBUTION SUBSYSTEMS
 - EOTV PROPULSION SYSTEM FOR
 - ORBITAL TRANSFER & RETURN
 - MPTS COMPONENT TEST SUBSYSTEM

Figure 2.2-10. MPTS Ground-to-GEO Microwave Test Elements



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Figure 2.2-11. Retro System Configuration Geometry



The ground-to-GEO 1-km-long linear transmitter array could be located in close proximity to dynamic test stand antenna installation, along a straight stretch of service road running east to west paralleling the southern fence-line of the MSFC facility as shown in Figure 2.2-12. This array would operate in conjunction with the proposed geosynchronous satellite test system for far-field microwave phase control evaluation testing.

The pilot-beam element of the GEOSAT system illuminates the ground antenna linear array, where the beam is received by the line-source retro-electronics which, in turn, phase the line source to return its beam to the GEOSAT. The beam is a fan beam since the line source aperture is a full-scale 1-km in the east-west direction, but only one power module wide (≈ 1 m) in the north-south direction.

The beam-mapping GEOSAT piggyback subsystem operates in a free-flying mode and probes the beam pattern by slowly drifting in an east-west pattern.

The GEOSAT test system is discussed separately in Section 2.6 because of its multi-mission characteristics as a general-purpose geosynchronous environmental test platform for all critical SPS subsystem elements.

2.3 POWER CONVERSION

The baseline photovoltaic energy conversion subsystem utilizes a GaAlAs solar cell with an efficiency of 20 percent at air mass zero (AM0) and 28°C, and requires 30.6×10^6 m² of solar cells (5-GW system). The most demanding requirement for SPS is the need for high-volume production of solar cells at very low costs.

The major assemblies that are required for the baseline photovoltaic subsystem are shown in Figure 2.3-1. The basic solar cell consists of GaAlAs junction, substrate, adhesive, current collectors, and anti-reflective coating. The solar blanket consists of a 25- μ m Kapton membrane upon which the cells are fastened with a thermo-setting FEP adhesive. Also included in the blankets are the interconnects, coatings required for thermal control, attachments, tensioning devices, and sensors. Thin concentrator membranes are used to reflect the sun onto the solar cell surface, and obtain nominal concentration ratios of 2. The concentrator is made of 12.5- μ m (0.5-mil) aluminized Kapton. Reflectivity is taken at 0.9 beginning of life (BOL), and 0.72 end of life (EOL). The membrane has a mass of 0.018 kg/m² and is mounted on the structure using attachments and tensioning devices.

Power conversion subsystem interfaces are shown in Figure 2.3-2. Switch gears are shown for clarity, although they are considered part of the power distribution subsystem. The major interfaces include the array orientation, attitude control, IMS and control, energy storage, power distribution, structure, thermal control, and support operations. The major interface parameters are also indicated. The proposed experiment/verification schedule for power conversion subsystem development is outlined in Figure 2.3-3.



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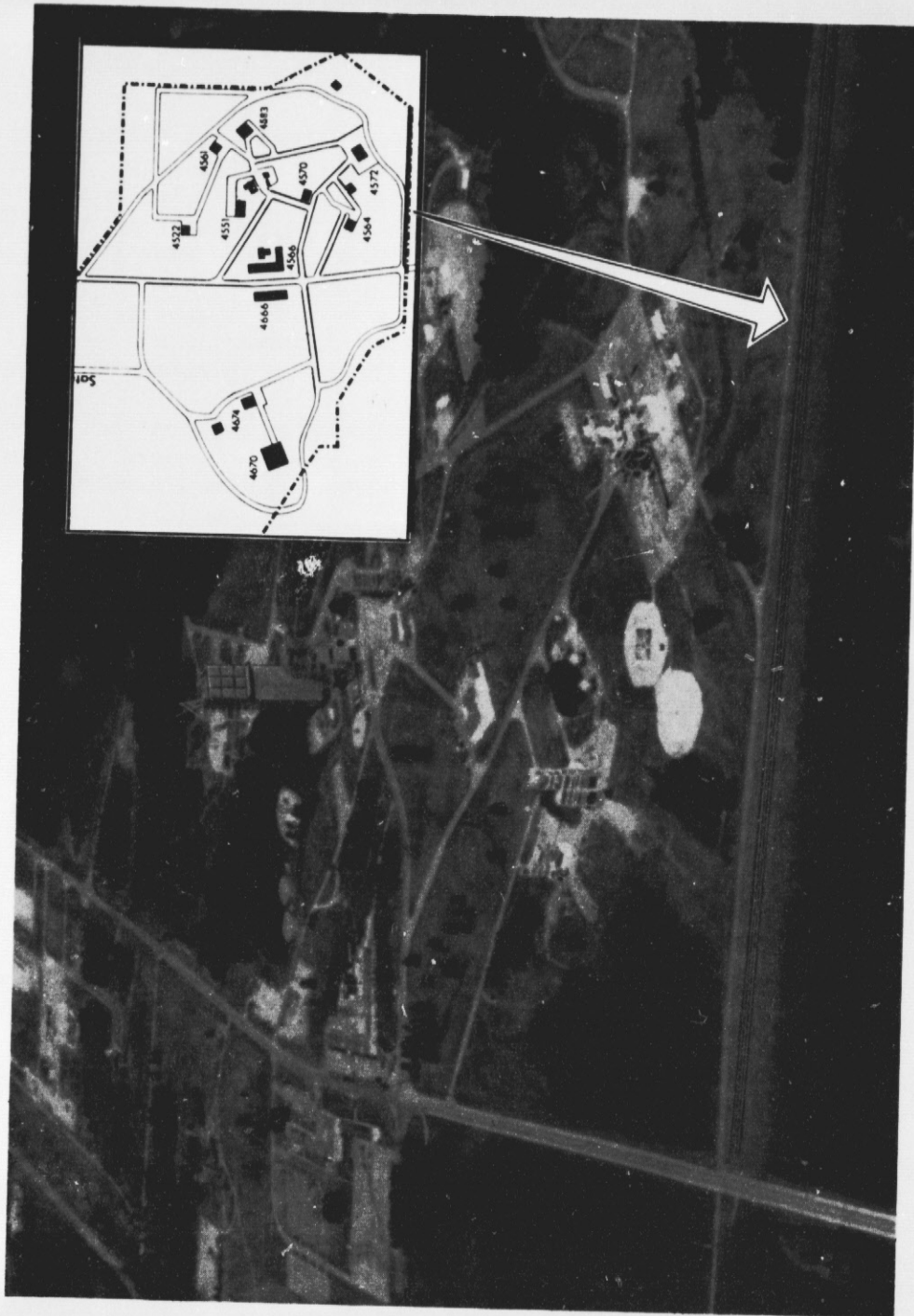


Figure 2.2-12. Phase B 1-km Linear Array Ground-to-Space Range

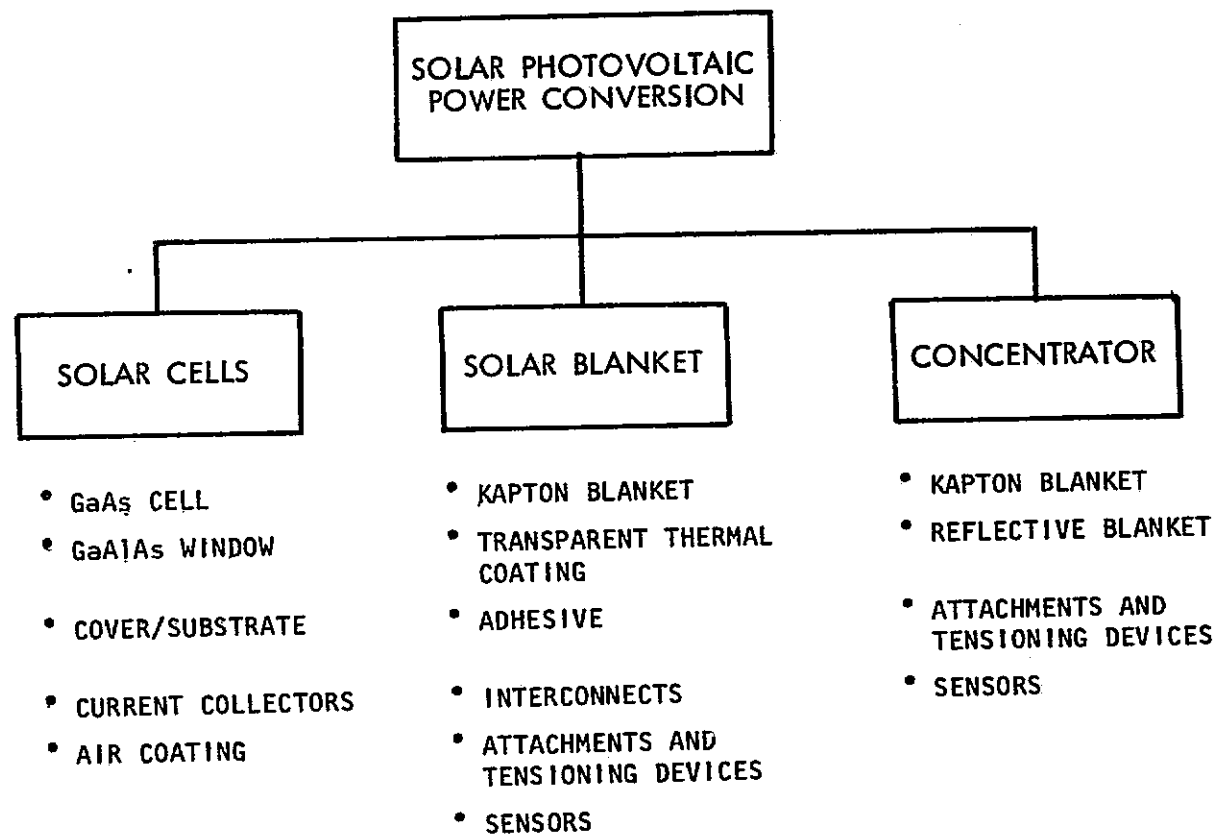


Figure 2.3-1. Solar Photovoltaic Power Conversion

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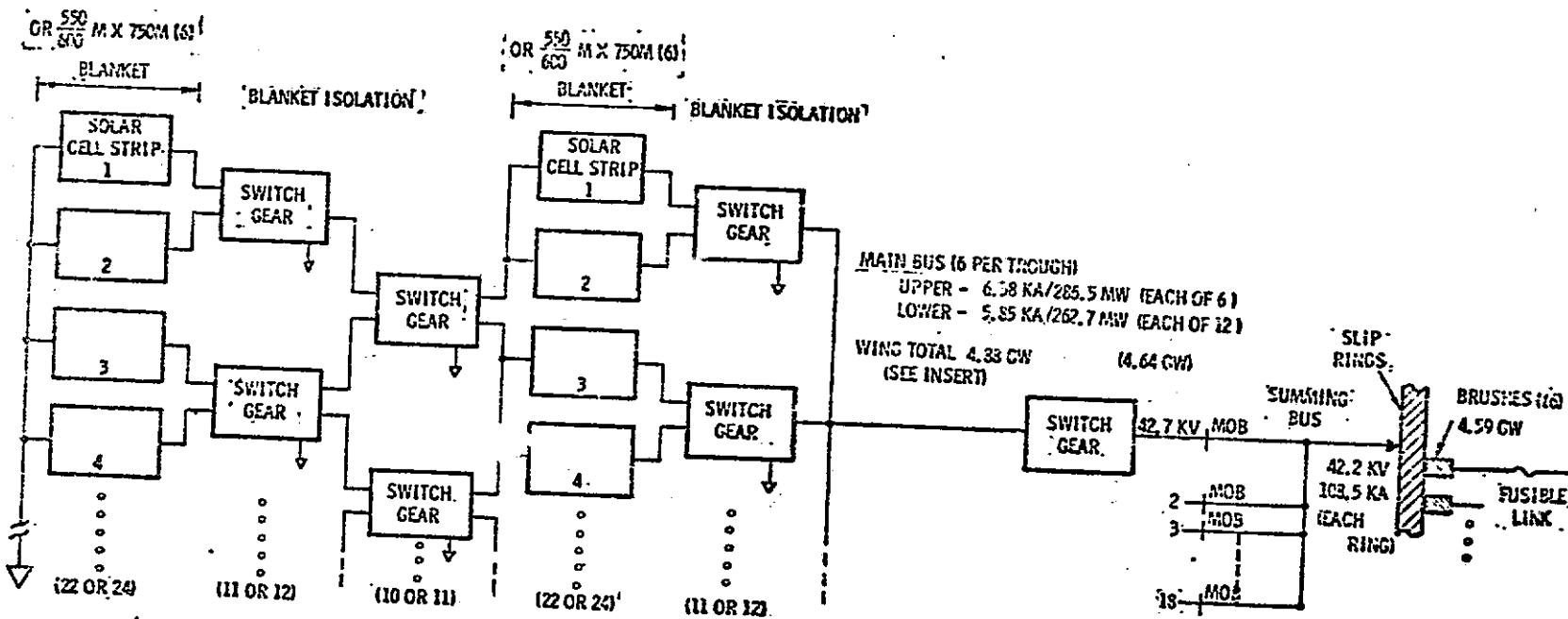
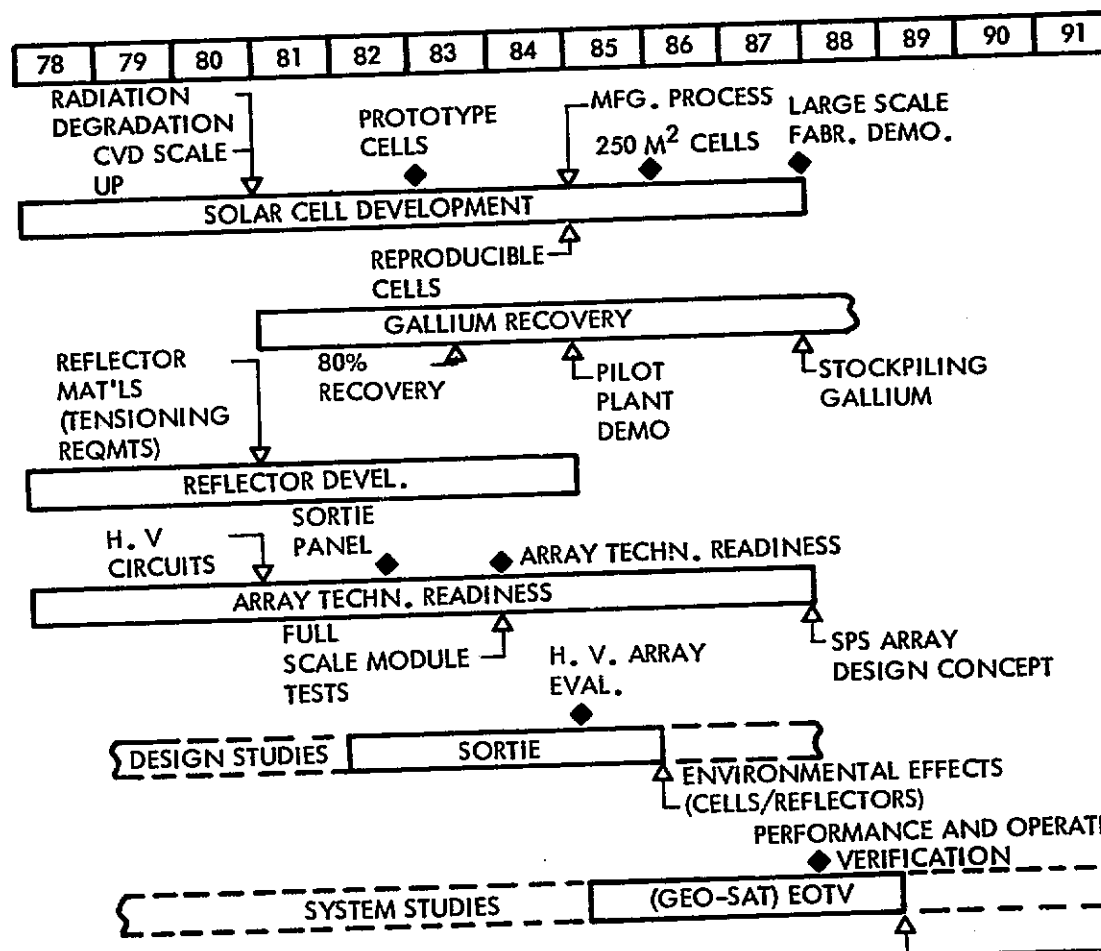


Figure 2.3-2. Power Conversion - Photovoltaic Block Diagram

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LONG DURATION -

- H.V. EFFECTS
- INTERACTIONS
- RADIATION DEGRADATION

Figure 2.3-3. Solar Photovoltaic Power Conversion Verification Schedule



Key milestones include availability of prototype cells at the end of 1982; array technology readiness demonstrated early in 1984; sortie high-voltage array evaluation by late 1984; and GEOSAT EOTV performance verification in space by late 1987.

The solar cell development includes 250 m of GaAlAs solar cells in late 1985 of a design that is reproducible and built to SPS specifications. These cells are to be used in the operational GEOSAT EOTV solar array.

The objective of this program is to provide the necessary technology verification that will permit an SPS program decision by late 1987.

The proposed integrated power conversion verification test plan is shown in Figure 2.3-4. Principal effort would concentrate on component development and integrated ground test elements while maintaining logical test sequences with respect to early experimentation tasks and sortie mission experiments. The component development phase includes the major solar cell development tasks, and begins the process of providing ample supply of gallium as part of component development. Solar array packaging of solar cells and reflectors would be developed. The integrated ground test activity would include a full-scale module ground test of the solar array. It is anticipated that technology readiness will be achieved for solar arrays with a power-to-weight ratio compatible to SPS requirements, i.e., ~650 W/kg.

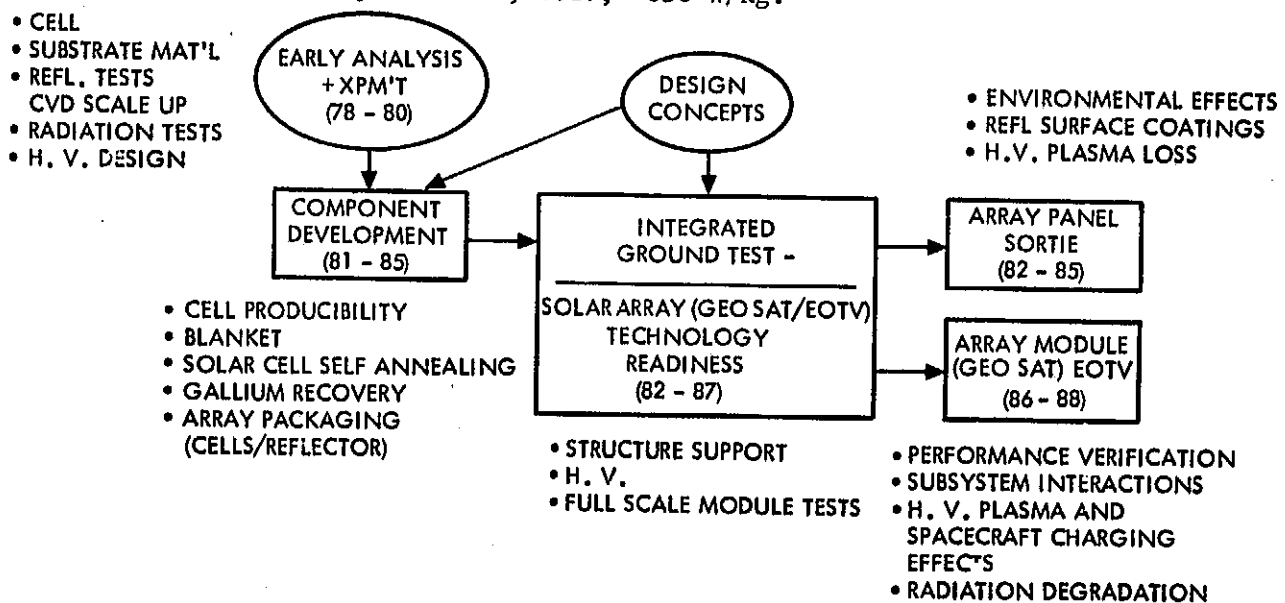


Figure 2.3-4. Power Conversion Early Verification Plan

A limited sortie test program is proposed, consisting of evaluation of environmental effects on solar cells and reflectors and high-voltage plasma losses.

A critical element in power conversion technology verification is an operational test of solar array, power distribution, control, and RF equipment loads in the geosynchronous environment. This test would be accomplished with the GEOSAT system described in Section 2.6.



2.3.1 SUPPORTING RESEARCH AND TECHNOLOGY (SRT)—EARLY ANALYSIS/EXPERIMENTAL RESEARCH

Past studies have shown that a GaAlAs solar array with concentration ratios of 2 to 5 result in an effective design concept for low weight and cost. The GaAlAs photovoltaic subsystem also has the potential for increased performance, higher resistance to ionized radiation levels, and the ability to operate with concentrators with minimum loss in performance compared to Si cells. Determination of the state of the art, analyses, computer modeling, design and tradeoff studies should be initiated and the results of these tasks used to define the fabrication, test, and development programs required for the major power conversion components. Major elements that require early investigation and advanced development to verify the design approach are shown in Figure 2.3-5.

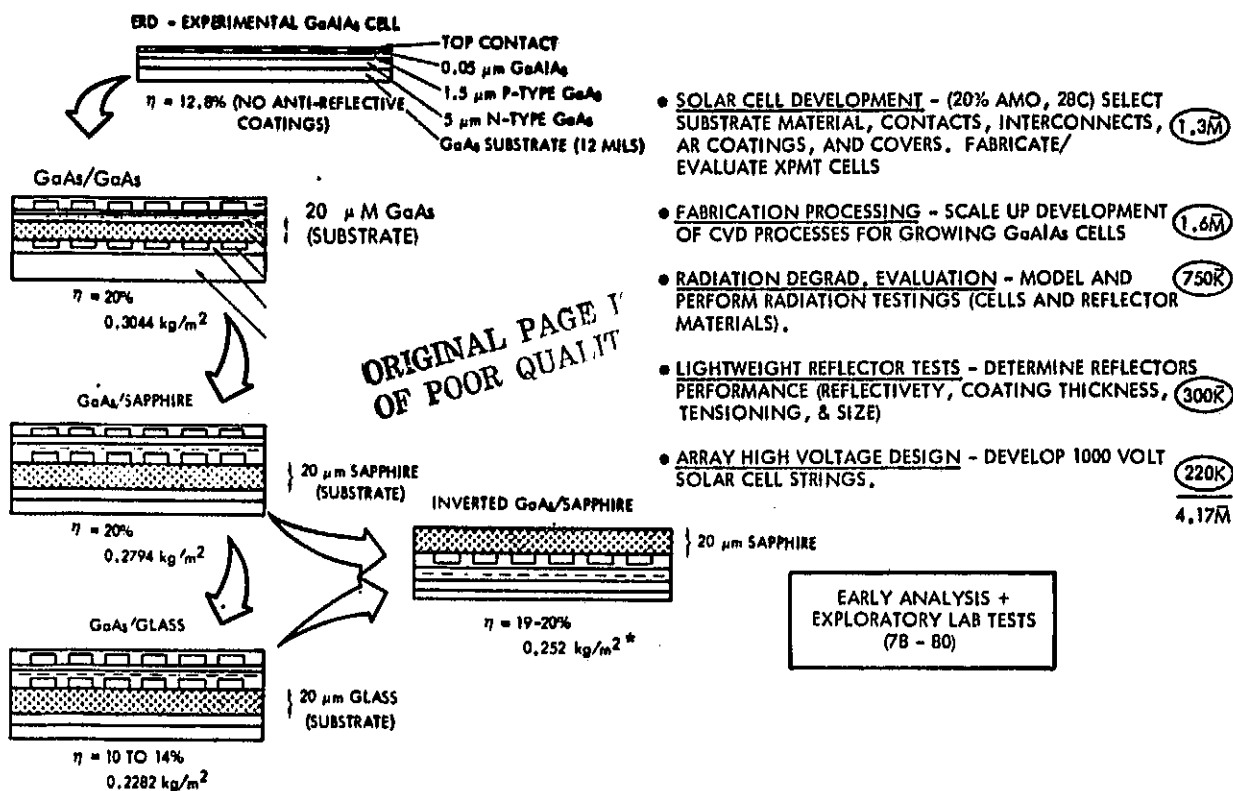


Figure 2.3-5. Photovoltaic Power Conversion Subsystem

The basic cell design is the inverted GaAs/sapphire design having a weight of 0.252 kg/m^2 . The various cell designs and the selected design are shown in the figure. The cell design has a 20- μm sapphire substrate upon which is grown a 5- μm single crystal GaAs junction. A 500-angstrom GaAlAs window is then deposited on the 5- μm junction

Early analysis and exploratory lab tests are planned to pursue the solar cell development. High efficiency is required to minimize solar cell area. A lower-cost substrate than gallium arsenide is needed to reduce solar cell costs. Present CVD reactor chambers are limited to the laboratory. Considerable scale-up is required, particularly to understand control of process variables at high production rates.



Radiation-resistant GaAs solar cells and self-annealing designs must be fully explored. Parameters for reflector design are needed to develop SPS array concepts. High-voltage solar cell string development must begin during this period.

The criticality of solar cells and reflector component elements relative to subsystem feasibility and efficiency requires significant early experimental research effort. Task descriptions, objectives, and experimental approaches for these early analysis tasks are described in Section 3.0 (Supporting Research and Technology Summary).

2.3.2 COMPONENT DEVELOPMENT

The proposed power conversion component development test plan is summarized in Figure 2.3-6. During this phase, solar cell development must progress to the point where manufacturers have achieved reproducible GaAlAs solar cells with high manufacturing yields. A prototype cell is required to support GEOSAT EOTV solar array development. Techniques will be developed for interconnecting solar cells to achieve high-voltage modules and cell laydown to the blanket.

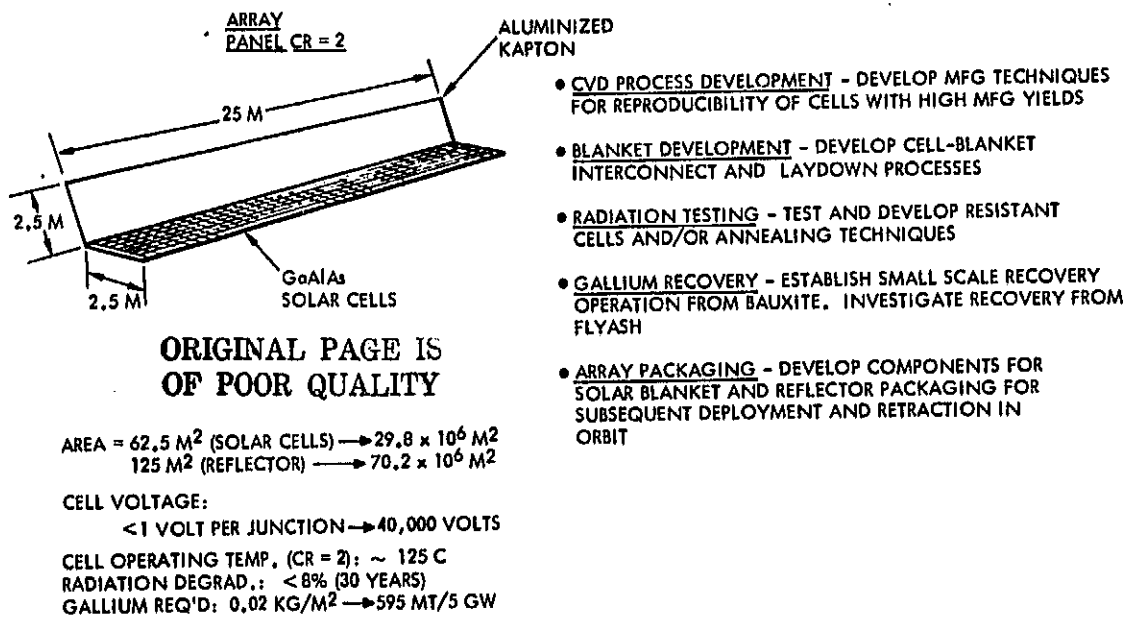


Figure 2.3-6. PC Component Development (1981-1985)

A small-scale pilot line development is proposed for gallium recovery. This will demonstrate 80-percent recovery from bauxite. Commercial demonstration of gallium recovery would follow an SPS decision to go operational.

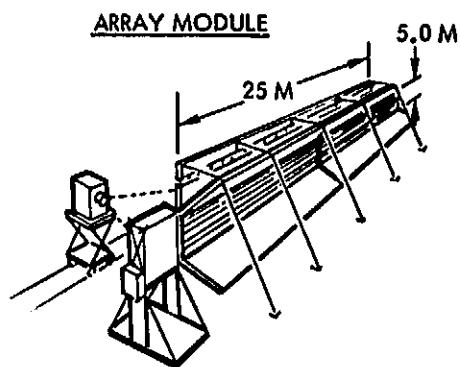
A critical element to an EOTV development is a radiation-hardened and/or self-annealing GaAlAs solar cell development. Preliminary assessments indicate that this might be achieved, and its pursuit is highly recommended during the component development phase.



Array packaging includes both the solar cells and associated reflectors. The first space test item (GEOSAT EOTV) will require deployment and retraction.

2.3.3 INTEGRATED GROUND TEST

This phase of early development is summarized in Figure 2.3-7, and represents the key activity to establish solar array technology readiness for a 1987 decision on SPS operational status. A full-scale blanket/reflector module test is proposed in a similar way to that achieved in the early Solar Electric Propulsion (SEP) program. This design will match SPS requirements as nearly as practical in terms of cell, reflector, and structural weights. The technology that results will be the basis of GEOSAT EOTV solar array design.



- REFLECTOR STRUCTURE SUPPORT - DETERMINE OPTICAL PERFORMANCES, STRUCTURAL RIGIDITY, AND MEMBRANE DEFLECTION, CREEP, AND TENSIONING REQMTS
- HIGH VOLTAGE ARRAY - CONFIGURE, TEST AND EVALUATE HIGH VOLTAGE SOLAR CELL STRINGS ON TYPICAL BLANKET AND STRUCTURE CONFIGURATION
- FULL SCALE BLANKET/REFLECTOR MODULE - DEVELOP AND CONFIRM ASSEMBLY, REPAIR, AND DEPLOYMENT CONCEPT OF SOLAR CELL BLANKETS AND REFLECTORS

SIZE: 50 KW
AREA: 125 M²
REFL. TENSIONING REQ'D: 10 - 1000 PSI
SUBSTRATE: 1 MIL KAPTON
REFL.: 1/2 MIL KAPTON
CELL: 1 MIL GaAlAs
WEIGHT: .252 KG/M² CELL → 7.5 (10⁶) KG
.019 KG/M² REFL. → 1.3 (10⁶) KG
.0135 KG/M² STRUCT. → 4.0 (10⁶) KG

*NOTE: ~ 5% SOLAR CELL COVERAGE

Figure 2.3-7. PC Integrated Ground Test (1982-1987)

Reflector structure support requirements will also be developed. A high-voltage array will be configured and evaluated. Vacuum tests will be required to eliminate aerodynamic effects during test evaluation.

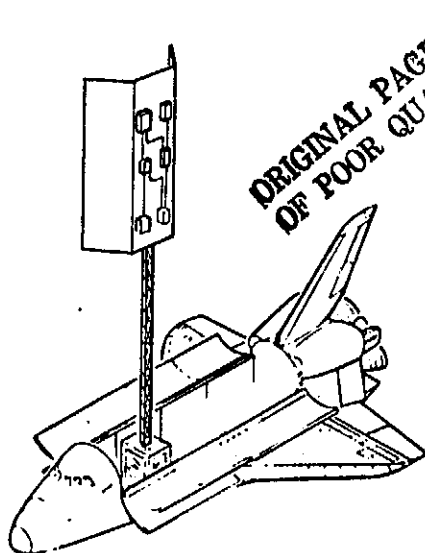
2.3.4 SPACE TEST PROGRAM

A basic developmental concept embodied in the baseline development plan scenario relates to the premise that most of the technology verification effort in support of key issue resolution can be accomplished through comprehensive analysis, and ground experimentation and development. The principal requirement for space testing is satisfied by the geosynchronous multimission concept of the GEOSAT, functioning in the operational environment of SPS systems.



There is, however, a significant requirement for selective LEO verification testing utilizing the Shuttle system in both shared and dedicated sortie modes.

In addition to geosynchronous orbital testing of power conversion subsystem elements using the GEOSAT test system (described in Section 2.6) key sortie experiments are also indicated as summarized in Figure 2.3-8. These proposed sortie tests could be combined with power distribution subsystem elements and would be limited generally to evaluation of space environmental effects. Since these tests are conducted in LEO and for short durations, the amount of radiation degradation that can be observed will be limited. On-orbit reflector performance evaluation to assess tensioning requirements on reflectivity will be extremely important to the design of large reflectors. It is very expensive to accomplish high tensioning and, at the present time, the SPS design concept is based on low-tensioning requirements.



SIZE: 3.5 KW
AREA: 8.5 M² CELLS
CELL EFFICIENCY: 18.5% (125 C)
REFLECTIVITY: 90% BOL

*NOTE: VOLTAGE 1000-5000 VOLTS

- SOLAR CELL SPACE ENVIRONMENTAL EFFECTS - ON-ORBIT CELL PERFORMANCE, DEGRADATION, CALIBRATION VERIFICATION OF MODELS
- REFLECTOR SPACE ENVIRONMENTAL EFFECTS - ON-ORBIT REFLECTOR PERFORMANCE, DEGRADATION, AND VERIFICATION OF MODELS
- SPACE MANUFACTURE - EXPERIMENT WITH REFLECTOR SURFACE MATERIALS APPLIED ON ORBIT
- HIGH VOLTAGE SOLAR ARRAY - ASSESS HIGH VOLTAGE - PLASMA DISCHARGE THRESHOLDS AND CHARACTERISTICS. DETERMINE DIELECTRIC CHARACTERISTICS OF ARRAY SUBSTRATE AND COVER
- PLASMA LOSSES AT HIGH VOLTAGE - INSERT PIN HOLES ON SEGMENTED FLAT CONDUCTORS TO EVALUATE PLASMA LOSSES AT HIGH VOLTAGE
- SUPERCONDUCTIVITY POWER CABLES* - OBTAIN DATA OF A SMALL SCALE SUPERCONDUCTIVE POWER CONDUCTOR AND EVALUATE PERFORMANCE CHARACTERISTICS

Figure 2.3-8. PC Sortie Experiments (1982-1985)

Reflector surface degradations could be excessive, and it is important to resolve this issue early in the design phase. Present allowances are made for a degradation of 20 percent over the 30-year lifetime, and this results in a solar cell area penalty of 6.1×10^6 m² per 5-GW system.

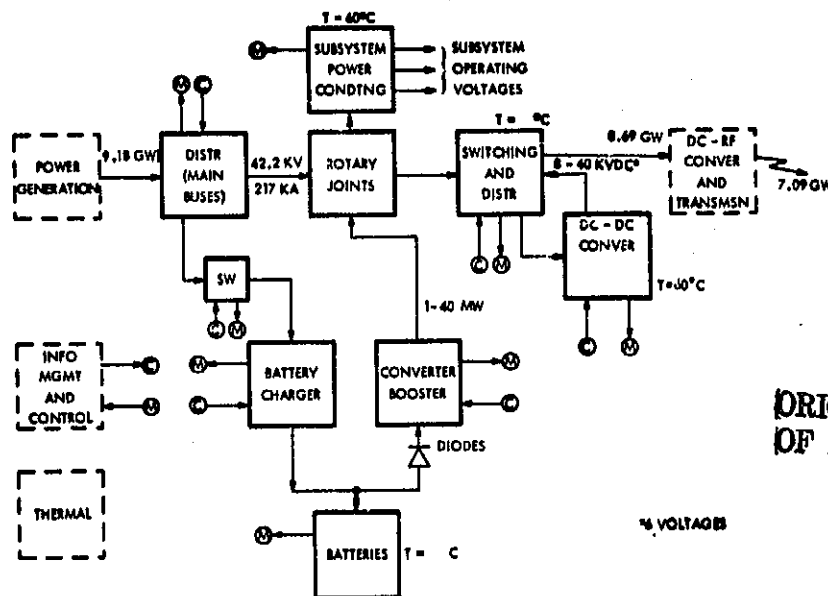
Existing data indicate that the SPS array voltage will be limited to <<40 kV in LEO because of high plasma losses; this necessitates two configurations since GEO operation is planned at 40 kV. Early space tests are



required to confirm plasma losses as a function of voltage and materials. More definitive sortie experiment concept definition is required, based upon preliminary point-design SPS system definition.

2.4 POWER DISTRIBUTION

The power distribution and control subsystem (PDS) receives power from the solar arrays and provides the energy storage, regulation, and switching required to deliver regulated power for distribution to the antenna system (klystrons) and the various subsystems (attitude control, information management and control, etc.). The grounding, electromagnetic interference control, and shielding requirements of the SPS are also included as part of the PDS. The functional block diagram for the power distribution subsystem is shown in Figure 2.4-1.



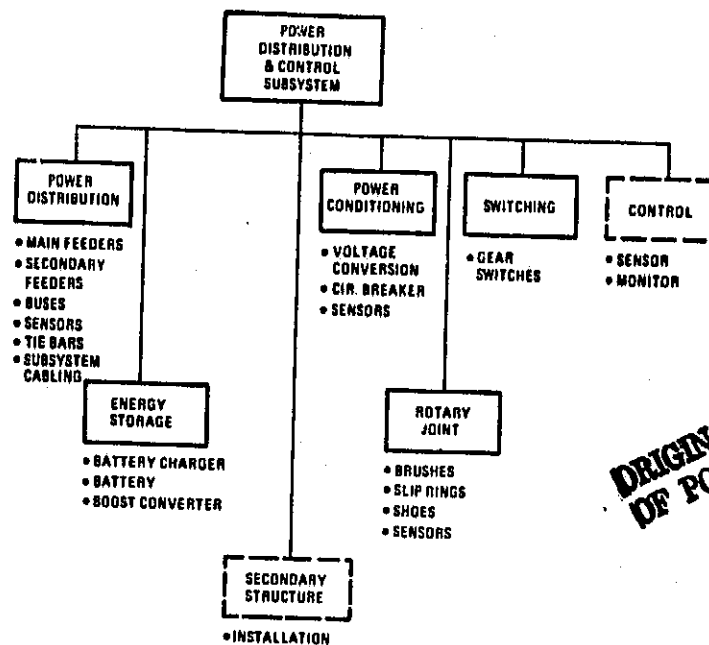
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Figure 2.4-1. Power Distribution and Control

Although subsystem power conditioning and dc-dc conversion are shown as being combined into a single unit, these functions are in actuality composed of many dc-dc converters located throughout the satellite and/or MW antenna structure.

The information management and control system (IMCS) monitors the bus as well as the regulator/converter voltages, currents and temperatures, and compares these with preset levels stored in the computer. In the event of a disagreement, the IMCS initiates a command signal to open up the associated switch bear.

The major assemblies comprising the power distribution and control subsystem (PDS) are shown in Figure 2.4-2. The power distribution consists of the main feeders, secondary feeders, summing buses, tie bars, and power



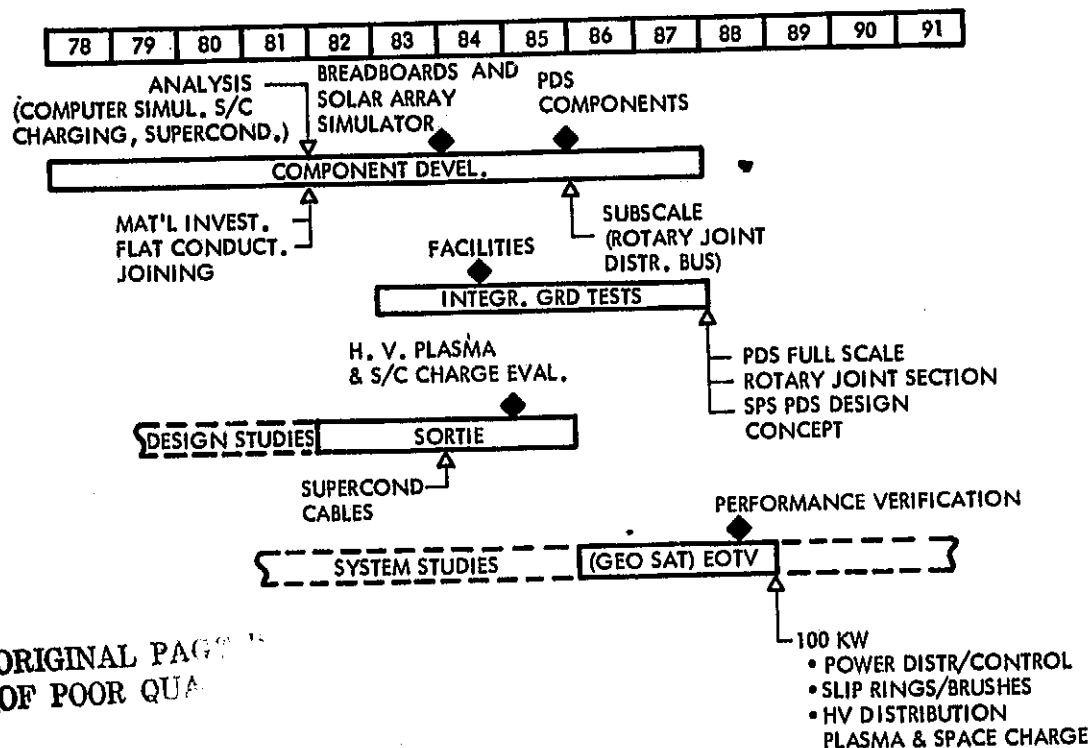
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Figure 2.4-2. Power Distribution Assembly Tree

interface cabling to the various subsystems. The power distribution utilizes flat aluminum (6001-T6) feeders where feasible. The flat conductors are not considered part of the main structure. The power converters and conditioners convert the existing bus voltages to the subsystem voltage required for the various subsystem loads. Switch gears are used on the array to achieve voltage regulation and power management elsewhere for circuit isolation and prevention of large line transients upon start-up and shutdown. Batteries will be utilized during eclipse periods to provide the minimum energy required by the various subsystems. The rotary joint is utilized to transfer energy through the slip rings and brushes from the SPS fixed member to SPS rotating member upon which the microwave antenna is located. The PDS control concept is a continuous monitoring system performed by the on-board IMCS computer system. Secondary structures consist of mounting brackets, clamps, and installation structure, as needed.

The proposed experiment/verification schedule for power distribution and control subsystem development is outlined in Figure 2.4-3. In the initial phase, emphasis is placed on computer modeling of PDS components and subsystems for determining performance characteristics. Subsequent phases consist of component development and verification, through integrated ground testing. Sortie experiments would be performed to obtain data under space environment for updating simulator model. The GEOSAT EOTV would provide system operational verification in conjunction with power conversion and transmission subsystem elements.

The proposed integrated power distribution verification test plan is shown in Figure 2.4-4. Development objectives consist of obtaining performance characteristics of power distribution component and overall subsystem models. Model verification will be accomplished through component hardware ground testing, supported by sortie and GEOSAT space experiments, in conjunction with power conversion subsystem testing.



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Figure 2.4-3. Power Distribution and Control Early Verification Schedule

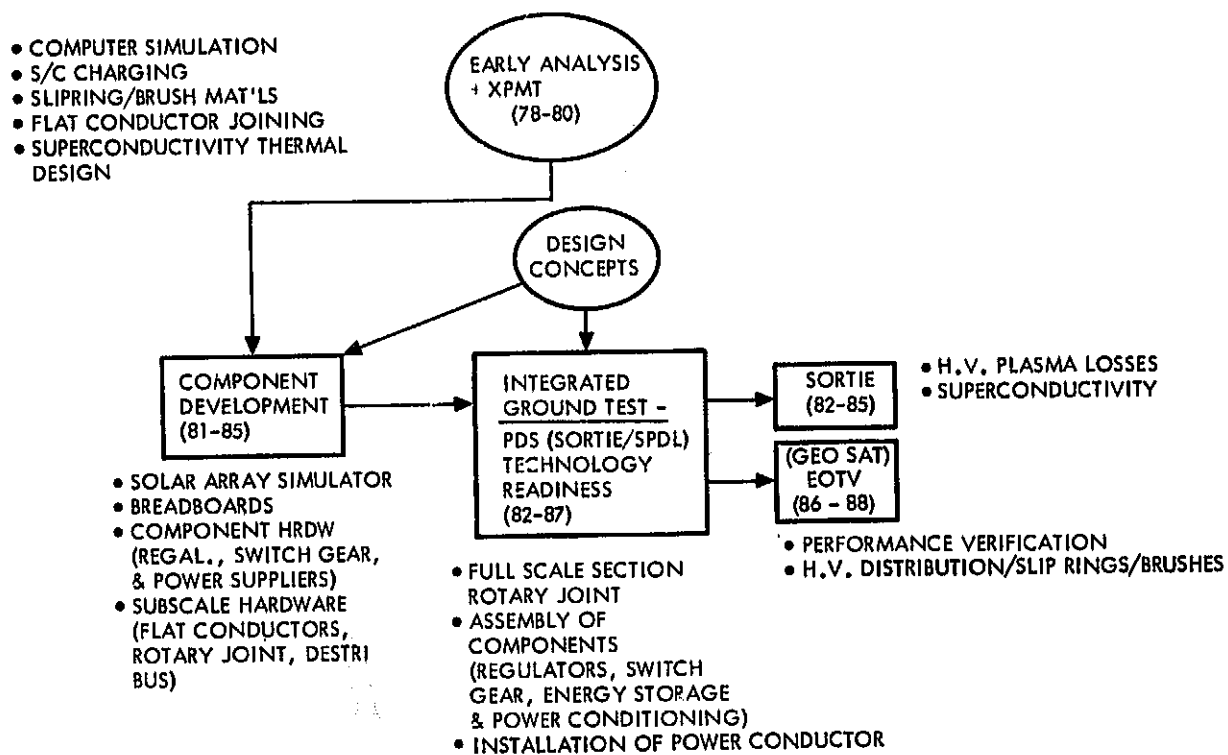


Figure 2.4-4. Power Distribution and Control Early Verification Plan



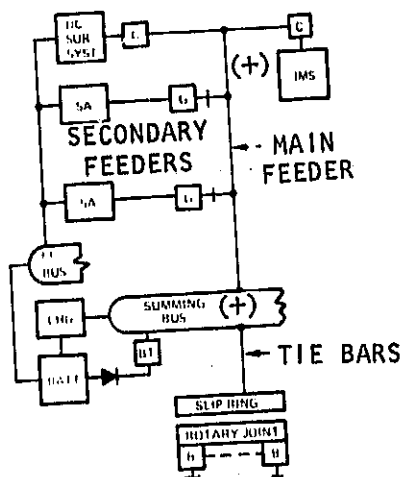
2.4.1 SRT—EARLY ANALYSIS/EXPERIMENTAL RESEARCH

A series of experimental research tasks are proposed for early technology feasibility investigation; these are summarized in Figure 2.4-5. The objectives of early experimentation tasks are listed below.

- Develop simulation models of subsystem components for determining performance characteristics.
- Develop simulation model of PDS subsystem.
- Perform steady-state, transient, short-circuit, and load-variation analyses on PDS subsystem model.
- Investigate protective devices for safety of equipment and personnel.
- Develop a computer model for investigating space charge effects.
- Perform analysis of superconducting power cables to determine whether they are feasible for SPS applications.
- Perform laboratory experiments of the various joining techniques of flat conductors, and determine slip-ring/brush, thermal, and electrical characteristics.

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Task descriptions and experimental approaches for these early analyses/experimental tasks are described in Section 3.0 (Supporting Research and Technology Summary).



- SIMULATION ANALYSIS - DEVELOP COMPUTER MODEL OF PDS AND PERFORM STEADY STATE AND TRANSIENT ANALYSIS. DETERMINE PROTECTIVE DEVICES, OPERATING STANDARDS, AND PERSONNEL SAFETY.
- SPACECRAFT CHARGING ANALYSIS - DEVELOP COMPUTER PROGRAM TO SIMULATE SPACECRAFT CHARGING EFFECTS. DETERMINE EFFECTS ON CIRCUIT COMPONENTS.
- SLIPRING/BRUSHES MATERIAL INVESTIGATION - INVESTIGATE VARIOUS MATERIALS TO DETERMINE THERMAL & ELECTRICAL CHARACT.
- FLAT CONDUCTOR JOINING PROCESSES - EXPERIMENTALLY DETERMINE JOINING TECHNIQUES (SEAL WELDING AND SLIP-JOINT TECHNIQUES).
- SUPERCONDUCTING POWER CABLES - INVESTIGATE THERMAL CONTROL CONCEPTS FOR MAINTAINING A SUPERCONDUCTIVE STATE OF CONDUCTOR ELEMENTS

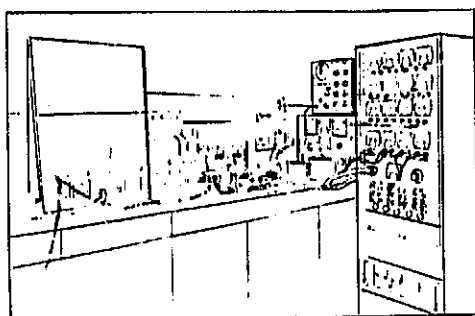
EARLY ANALYSIS +
EXPLORATORY LAB TESTS
78 - 80

Figure 2.4-5. Power Distribution and Control Subsystem Research Tasks



2.4.2 COMPONENT DEVELOPMENT

Proposed power distribution component development plan elements are summarized in Figure 2.4-6. The objective is to develop and verify performance of new high-power (high-current/high-voltage) components which represent advance technology for utilization in the PDS system of the SPS concepts. The component design concepts will be breadboarded to prove out the theory as well as to verify performance characteristics. Actual SPS full-scale components will be included in the development tasks. A solar array simulator would be developed for evaluating subsystem electrical characteristics, and major subsystem components will be breadboarded and tested to provide experimental data for solar simulation modeling. Rotary joint slip-ring elements, flat conductors, high-voltage regulators, and solid-state switch gear and power supplies will be developed and tested.



SOLAR CELL I-V: 0.612V PER CELL (50,000 VOLTS)
ROTARY JOINT: 7.75 AMPS/CM² (BRUSHES)
CONDUCTORS: 0.1 CM THICK
SWITCHGEAR: 10000 AMPS
DISTR. BUSSES: 100,000 AMPS

- SOLAR ARRAY SIMULATOR - DEVELOP A SOLAR ARRAY SIMULATOR FOR EVALUATING SUBSYSTEM ELECTRICAL CHARACTERISTICS
- BREADBOARD SUBSYSTEM COMPONENTS - BREADBOARD VARIOUS COMPONENTS (SWITCHGEAR, REGULATOR, DC TO DC CONVERTER) FOR OBTAINING DATA COMBINATION WITH SOLAR SIMULATION MODEL
- ROTARY JOINT SUBSCALE HARDWARE - TEST SLIP RING SECTION (THERMAL & ELECTRICAL CHARACT., BRUSH RATE OF WEAR, MONITORING/CONTROL, AND MANUFACTURING PROCESSES)
- SUBSECTION FLAT CONDUCTORS - DEVELOP TECHNIQUES, PROCESSES AND TOOLING REQMTS FOR MANUFACTURE OF FLAT CONDUCTOR SECTIONS
- HIGH VOLTAGE REGULATOR - DEVELOP HIGH VOLTAGE REGULATION OF SOLAR ARRAY POWER
- SWITCH GEAR AND POWER SUPPLIES - DEVELOP HIGH POWER SWITCH GEAR FOR INTERRUPTION OF POWER OF SOLAR OF POWER OF SOLAR ARRAYS FOR ISOLATION AND/OR MAINTENANCE
- DISTRIBUTION BUS FABRICATION - DEVELOP TECHNIQUES FOR PROCESSING AND TOOLING FOR MANUFACTURE OF BUSES

Figure 2.4-6. PDS Component Development (1981-1985)

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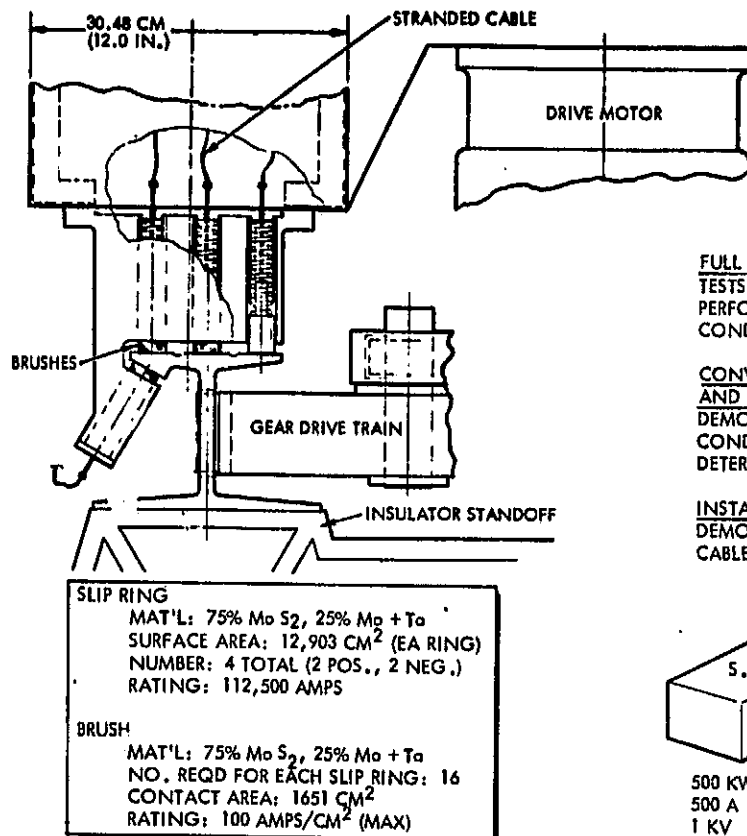
2.4.3 INTEGRATED GROUND TEST

This phase of early development is summarized in Figure 2.4-7, and will consist of verification of design concepts and evaluation of hardware performance to establish specification parameters as related to subsystem performance requirements. Integrated ground testing will be conducted first in an ambient laboratory environment and, ultimately, in simulated space environment and tested in conjunction with power conversion subsystems as described in the previous section (Section 2.3). A full-scale prototypical rotary joint section would be constructed, as shown in the figure, as a basis for testing to verify assembly/maintenance/performance of the joint under ambient and thermal conditions. Tests would be conducted to verify and demonstrate



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integrated subsystem prototype design concepts and the performance of switch gear, regulators, batteries, and conditioning components. EMI filtering requirements would be derived from these laboratory tests.



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FULL SCALE SECTION ROTARY JOINT - CONDUCT TESTS TO VERIFY ASSEMBLY/MAINTENANCE/ PERFORMANCE OF ROTARY JOINT UNDER THERMAL CONDITIONS

CONVERTERS, SWITCHGEAR, ENERGY STORAGE, AND CONTROL - CONDUCT TESTS TO DEMONSTRATE AND VERIFY THE DESIGN CONCEPT CONDUCT SWITCH GEAR OPERATIONS AND DETERMINE EMI FILTERING REQUIREMENTS.

INSTALLATION OF POWER CABLES - DEMONSTRATE ABILITY TO INSTALL POWER CABLES AND MAINTENANCE PROCEDURES

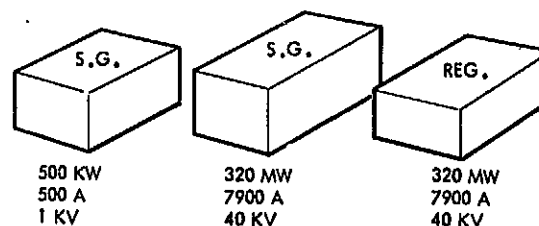


Figure 2.4-7. PDS Integrated Ground Test

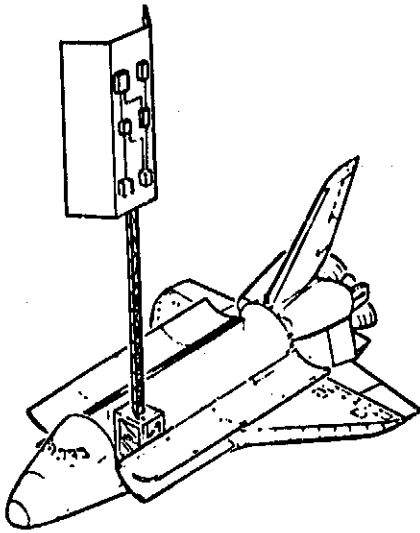
2.4.4 SPACE TEST PROGRAM

Laboratory and environmental testing of power distribution components and integrated subsystem elements would be followed by final in-site space verification demonstrations utilizing the GEOSAT multi-test system and selective Shuttle sortie experiments. GEOSAT testing will be discussed later in Section 2.6.

Proposed power conditioning sortie experiments would be designed to perform testing under space environments to obtain data on high-voltage plasma losses and spacecraft charging which cannot be obtained through ground testing. The data would be utilized to improve design concepts and for improving circuit designs. It is likely that these experiments can be planned and conducted in conjunction with power conversion subsystem sortie experiments in a single dedicated sortie mission. More detailed sortie mission concept definition is required when system and subsystem point-design and operational parameters and requirements are established as system baselines. Proposed sortie experiments are outlined in Figure 2.4-8.



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- PLASMA LOSSES AT HIGH VOLTAGE - INSERT PIN TITLES ON SEGMENTED FLAT CONDUCTORS TO EVALUATE PLASMA LOSSES AT HIGH VOLTAGE
- SUPERCONDUCTIVITY POWER CABLES* - OBTAIN DATA OF A SMALL SCALE SUPERCONDUCTIVE POWER CONDUCTOR AND EVALUATE PERFORMANCE CHARACTERISTICS

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SIZE: 3.5 KW
VOLTAGE: 1000 VOLTS - 5000 VOLTS

*DEPENDS ON RESULTS OF EARLY ANALYSIS

Figure 2.4-8. PDS Sortie Experiments

A superconductive experiment to obtain data on power transfer at critical superconductive temperatures should be considered for implementation. Definition of this experiment will depend upon concept feasibility laboratory testing in the early experimental research program.

2.5 STRUCTURE/ASSEMBLY

Developing the capability for fabrication and construction of very large low-density structures in space is an inherent requirement for the SPS program. The degree to which ground development and demonstration of SPS-type structure can be accomplished is necessarily limited by the sizes and mass involved, and the effect of a 1-g environment. The structures subsystem, therefore, requires a much higher proportion of space development activity as compared with hardware ground testing. A balanced, progressive program of ground and space testing provides a cost-effective method for resolving the critical technical issues involved.

Currently postulated structures subsystem critical technology development plan task elements are summarized in Table 2.5-1. The development test logic flow for this subsystem area involves a strong interaction between analysis and the math modeling effort recommended for early experimental research and subsequent structural ground testing of basic structural elements and integrated beam/girder components.



Table 2.5-1. SPS Subsystem Critical Technology Development Summary

EARLY DEVELOPMENT PHASE	CRITICAL TECHNOLOGY ITEM
EARLY ANALYSIS/ EXPLORATORY LAB TESTS 1978-1980	• STRUCTURAL DESIGN CRITERIA & VERIFICATION • MATERIALS DEVELOPMENT • NUMERICAL CHARACTERIZATION • CONSTRUCTION EQUIP. DEVELOPMENT • ATTITUDE CONTROL TECHNIQUES FOR VERY LARGE FLEXIBLE STRUCTURES • ACS ELECT. PROP. SYS. DEVELOPMENT
COMPONENT DEVELOPMENT 1981-1985	• CONST. EQUIP. DESIGN, FAB & CHECKOUT • STRUCTURAL ELEMENT VERIFICATION TESTS
INTEGRATED GROUND TESTING 1982-1987	• INTEGRATED CONSTR. EQUIP & STRUCTURE FAB, TEST & CHECKOUT
SHUTTLE SORTIES (SHARED & DEDICATED) 1982-1987	• MATERIAL AGING CHARACTERISTICS (SHARED) • ON-ORBIT FAB & TEST • ON-ORBIT ANTENNA STRUCTURE FAB & TEST (DEDICATED)

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The progressive development flow from early experimental research through component element development, integrated low-g ground test and, ultimately, full-scale orbital assembly demonstrations is summarized in Figure 2.5-1.

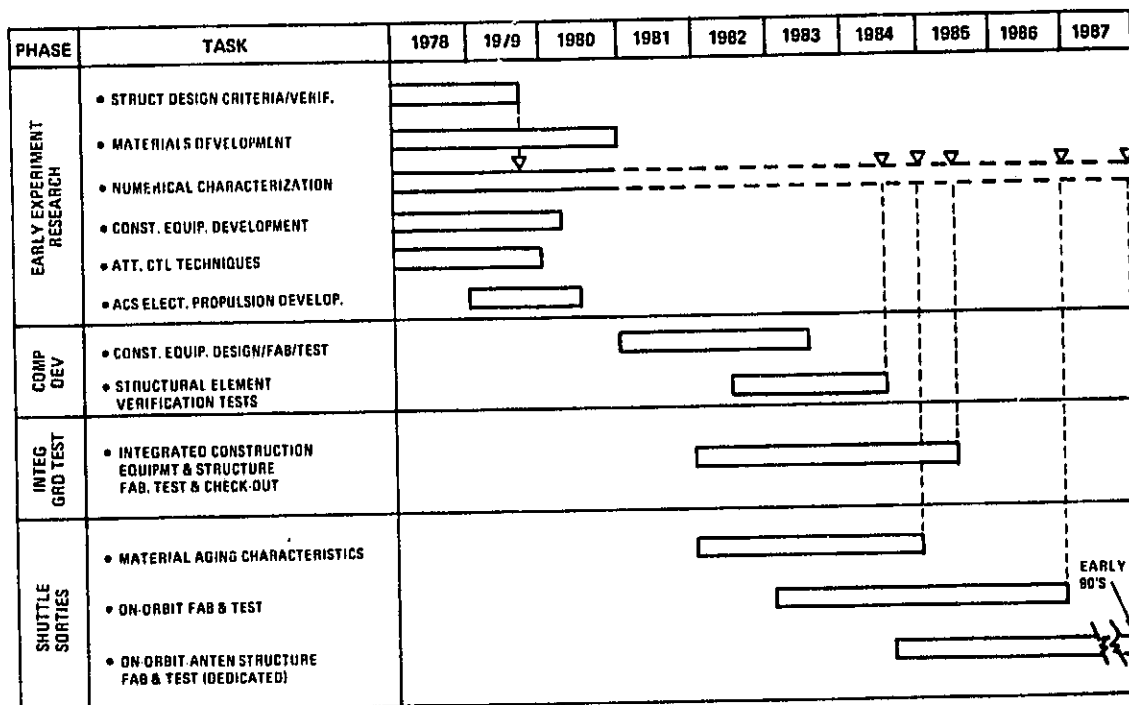


Figure 2.5-1. SPS Structures Subsystem Critical Technology Development Schedule



2.5.1 SRT—EARLY ANALYSIS/EXPERIMENTAL RESEARCH

Proposed early analysis/exploratory research tasks are outlined in Table 2.5-2, and further described below.

Table 2.5-2. SPS Structures Subsystem Early Analysis/Experimental Research Tasks

<u>STRUCTURAL DESIGN CRITERIA AND VERIFICATION</u> TASK DESCRIPTION ✓ DEVELOP CRIPPLING ALLOWANCE FOR SPS ULTRA-THIN-WALLED SHAPES BY TEST ✓ DETERMINE IMPACT OF INITIAL IMPERFECTIONS, OR ECCENTRICITIES AND TEMPERATURE DELTAS ON STRUCTURAL SUBELEMENT PERFORMANCE ✓ OPTIMIZE SUBELEMENT SHAPE BY COMBINATION OF TEST AND ANALYSIS ✓ DEVELOP DETAILED SUBELEMENT JOINT DESIGN
<u>MATERIALS DEVELOPMENT</u> TASK DESCRIPTION ✓ DEVELOP DESIGN DATA FOR THERMOPLASTIC COMPOSITE SYSTEMS (E.G., GRAPHITE/POLYSULFONES) ✓ DEVELOP WELDING AND FORMING PROCESSES FOR COMPOSITE SYSTEMS AND METALLICS MOST COMPATIBLE WITH ON-ORBIT FABRICATION
<u>NUMERICAL CHARACTERIZATION</u> TASK DESCRIPTION ✓ MODEL SUBELEMENT (STRESS) ✓ MODEL BASIC BEAM (STRESS AND DYNAMIC) ✓ MODEL TRI-BEAM GIRDER (STRESS AND DYNAMIC) ✓ MODEL ANTENNA STRUCTURE ✓ UPDATE AND REFINER MODELS BASED ON TEST DATA ✓ MODEL SPS SATELLITE (STRESS AND DYNAMIC) NOTE: THIS TASK EXTENDS INTO THE LATE 1980'S AS IT RELIES ON RESULTS FROM GROUND AND ORBITAL TEST PROGRAMS
<u>CONSTRUCTION EQUIPMENT DEVELOPMENT</u> TASK DESCRIPTION ✓ DEVELOP DETAILED SPS CONSTRUCTION SCENARIO ✓ IDENTIFY CONSTRUCTION EQUIPMENT AND DEVELOPMENT DESIGN CONCEPTS ✓ DEVELOP GROUND AND LEO VERIFICATION PLAN
<u>ATTITUDE CONTROL TECHNIQUES FOR VERY FLEXIBLE LARGE STRUCTURES</u> TASK DESCRIPTION ✓ DEVELOP PREFERRED STRUCTURAL DYNAMIC MODELING, INCLUDING THERMAL BENDING EXCITATION OF STRUCTURE ✓ DEVELOP ATTITUDE CONTROL POLICIES AND TECHNIQUES TO MINIMIZE STRUCTURAL EXCITATION; PROVIDE ACTIVE STRUCTURAL DAMPING AND MINIMIZE STRUCTURAL BENDING FREQUENCY REQUIREMENTS ✓ DEFINE GROUND AND SPACE TESTING PROCEDURES NECESSARY TO CONFIRM STRUCTURAL DYNAMIC CHARACTERISTICS
<u>ACS ELECTRIC PROPULSION SYSTEM DEVELOPMENT</u> TASK DESCRIPTION: DEVELOP DESIGN OF ION THRUSTER WITH FOLLOWING FEATURES: ✓ DEVELOP DESIGN OF ION THRUSTER WITH FOLLOWING FEATURES • LONG LIFE (>30 YEARS) • HIGH I_{sp} (>10,000 SEC) • MINIMUM POWER PROCESSOR REQUIREMENTS (I.E., DIRECT FROM SOLAR ARRAYS) • OPTIMIZED ENVELOPE SIZE • MINIMUM CONTAMINATION



2.5.2 STRUCTURAL DESIGN CRITERIA AND VERIFICATION

This task addresses the development of the cap section of a triangular beam element produced by a beam machine, as shown in Figure 2.5-2. These caps are basically compression columns made up of closed sections with lightening hole cutouts incorporated to produce maximum radius of gyration (ρ) for a given equivalent cross-sectional area. Failure of this cap can occur due to a variety of mechanisms such as local buckling (crippling), column buckling of either the overall section or the elements between cutouts, torsional instability, or a combination of the above. Developing an ultra-thin-walled cap section must consider not only the basic failure mechanisms described above, but also the detrimental effects of initial imperfections and/or eccentricities introduced during the fabrication processes and the temperature gradients across the section due to shadowing in both the construction and operational environments. The objective of this task is to develop an optimum section based on test and analysis, that considers the above factors, the ability to fabricate same on orbit, and joining concepts.

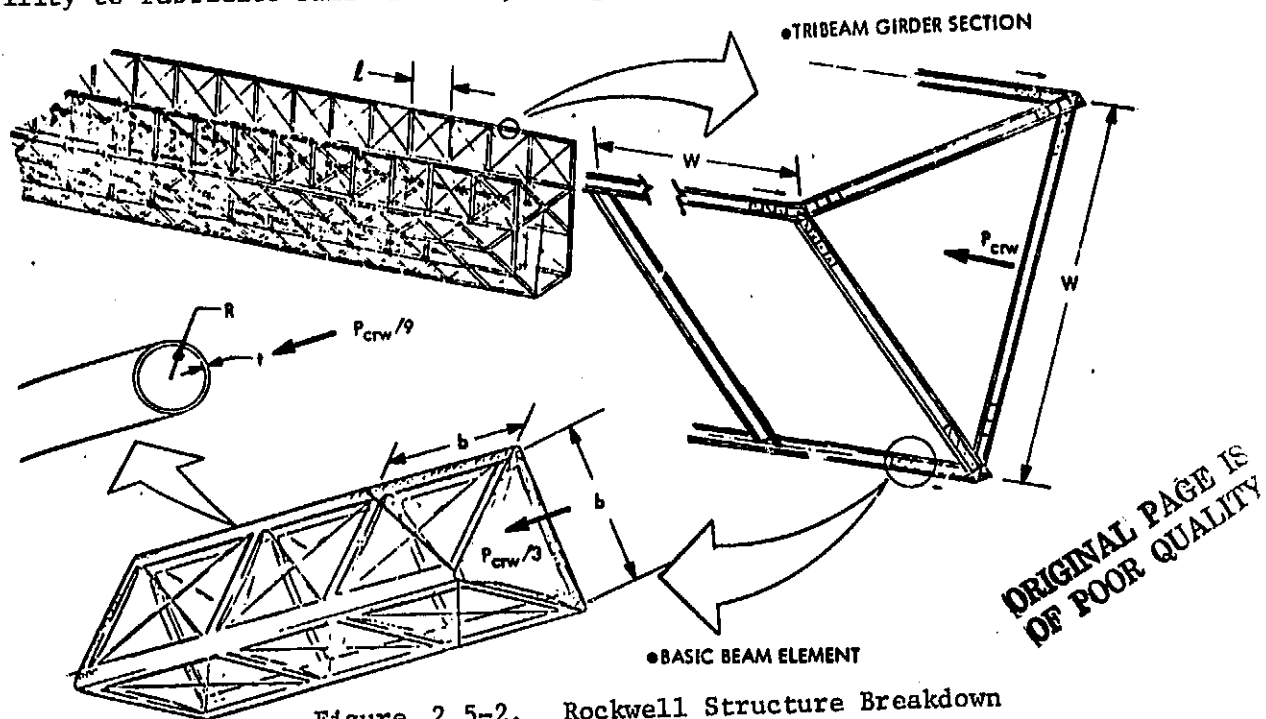


Figure 2.5-2. Rockwell Structure Breakdown

2.5.3 MATERIAL DEVELOPMENT

Composite systems, particularly thermoplastic systems, have a high potential for extensive application to SPS structures because of their high specific strength, low thermal expansion coefficient (α), and the low energy required to weld and form them. Mechanical and chemical properties for candidate thermoplastic systems, such as graphite/polysulfone, must be defined to a level of depth similar to those developed for structural aluminum in MIL-HDBK-5.



2.5.4 NUMERICAL CHARACTERIZATION

Highly accurate predictions of structural performance from the initiation of on-orbit construction to operational end of life must be developed via finite element computer models. The techniques for constructing these finite element models are available, but have not been applied or verified for large space lightweight structures like SPS. Numerical models of the simplest element up to and including a complete SPS structural system should be constructed in the early period of SPS development. These models should be continuously updated, based on ground and orbital test results. Assembly tolerance, joint effects, thermal distortion, and unique crippling capability are a few of the easily definable effects which will cause modification to the models as a result of ground and orbital testing.

2.5.5 CONSTRUCTION EQUIPMENT DEVELOPMENT

A construction scenario which describes an SPS fabrication and assembly sequence down to the "nuts and bolts" level is required. From this scenario, the required construction and support equipment can be identified and detailed design concepts generated. This approach is necessary in the early period of SPS development to assure that all equipment, such as the beam machine, that requires technology development and/or qualification is identified and that a plan for detail design, fabrication and ground/orbital verification testing is laid out consistent with the overall development schedule.

2.5.6 ATTITUDE CONTROL TECHNIQUES FOR FLEXIBLE LARGE STRUCTURES

The very large SPS structure results in orders of magnitude lower bending frequencies than contemporary spacecraft, and can approach the environmental disturbance frequencies. The development of new attitude control logic, compensation, and mechanization techniques are necessary to permit satisfactory control when bending frequencies are within the required control bandwidth. These techniques include *independent mode control*, *distributed actuators*, and the use of observers or estimators to support the active mode control policies.

The lightweight structure employed in SPS has thermal response time constants that are considerably smaller than the structural bending time constants. Hence, the thermal bending due to earth shadowing can be a major disturbing influence to structural excitation and the attitude control system. For this reason, new structural dynamic/control system modeling must be developed which incorporates the thermal bending disturbance source.

2.5.7 ACS ELECTRIC PROPULSION DEVELOPMENT

Work performed has illustrated that high-performance (high specific impulse) electric thruster technology is required to prevent very large and costly RCS propellant resupply requirements that result from attitude control and stationkeeping requirements over the projected 30-year SPS lifetime. Improved thruster lifetimes, relative to current laboratory thrusters, are also required to prevent excessive on-orbit maintenance requirements.



2.5.8 COMPONENT DEVELOPMENT

The component development phase would extend the early construction equipment concept development and design effort into the prototype hardware phase including detail design and fabrication of initial prototype hardware for test and checkout, and production of required beam elements for use in ground structural element verification tests. The following two general tasks are proposed.

Construction Equipment Fabrication and Checkout. This effort is essentially a Phase C/D for the construction equipment identified and conceptually designed in early concept development. Fabrication is limited to the equipment that is either totally, or at the component level, an advancement in the "state of the art" and requires demonstration, verification, and/or qualification. Test and checkout is initially limited to ground test and the definition of orbital test requirements. Fabrication of sufficient beam elements to support structural element verification is also part of this task.

Subtask elements would include:

- Detail design and fabricate one set of construction equipment (beyond "state of art" only; multiple beam builders may be required).
- Test and checkout of equipment amenable to ground test.
- Fabrication of a sufficient quantity of beam elements to support structural integrity ground testing.

Structural Element Verification Tests. This task is typical of any structural verification or qualification program undertaken in the aerospace industry, except that the test configuration and test conduct must either eliminate the effects of a 1-g environment or allow post-test analytical modification of the test results. This testing will be limited to beam element hardware developed earlier. Test results will be fed into the appropriate finite element models to verify simulation results.

Subtask elements would encompass the following:

- Conduct compression, bending, torsion, and combined load tests of beam elements fabricated during construction equipment development.
- Conduct frequency response tests, and develop structural element frequency characteristics.
- Update computer models.

2.5.9 INTEGRATED GROUND TESTING

Structures integrated ground testing needs to be developed in further depth, but should be planned to make use of existing NASA/industry test



facilities. This test effort would combine beam elements for the first time, and verify beam element to beam element joining techniques. Subsequent to fabrication and assembly technique development, structural testing would be conducted to develop joint action and efficiency data in support of finite element models. Developmental test effort could involve the fabrication of a scaled-down tri-beam girder transverse frame on an air-bearing table utilizing beam machines, applicable jigs, articulators, and other joining tools.

Fabrication of a typical SPS three-dimensional joint is also visualized, using neutral buoyancy facilities as shown in Figure 2.5-3. Specific structures integrated ground test experiment definition will depend upon point design structure characteristics and specifications, and upon detailed guideline SPS construction scenarios still in development.

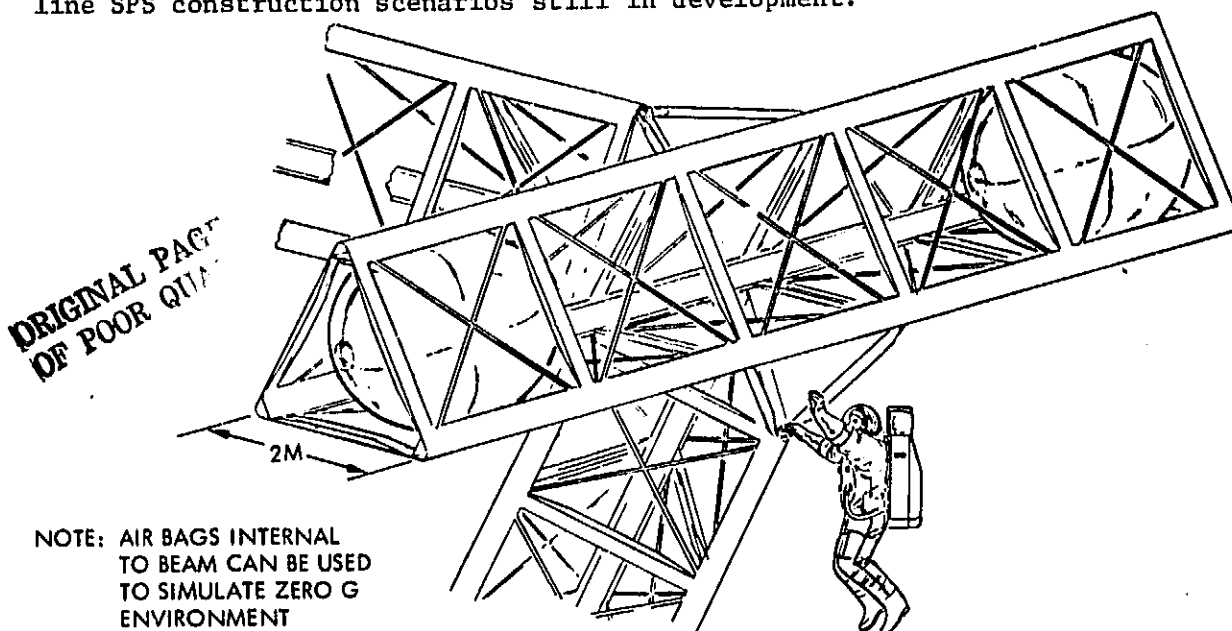


Figure 2.5-3. Neutral Buoyancy Tank Joint Test Specimen

2.5.10 SPACE TEST PROGRAM

Orbital structural fabrication and assembly techniques utilizing automated beam machines and tri-beam girder assembly equipment are key elements in verification planning and must, ultimately, be demonstrated in the zero-g environment. These orbital experiments/demonstrations would be conducted from baseline and extended-duration orbiters, and would progress from early "suit case" construction equipment-joining and fabrication experiments through full-scale SPS structural element fabrication, and two-meter beam fabrication to more complex full-scale tri-beam construction operations, and utilization of the assembled tri-beams for prototype MPTS antenna construction and major vehicle construction fixtures. Two major task elements are proposed, as discussed below.

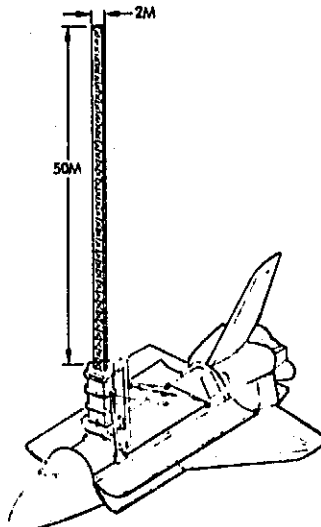
Orbital Fabrication and Test. This task would compose two major orbital test experiments. The first is a shared Shuttle sortie mission that fabricates



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and tests a 50-m basic beam element utilizing a beam machine that has previously been qualified by ground test. Compression, torsion, and frequency response testing can be accomplished using chemical thrusters with the same propulsive characteristics as the ion thrusters being developed for the SPS program. Test results will be fed into finite element models. This proposed sortie mission is depicted in Figure 2.5-4.

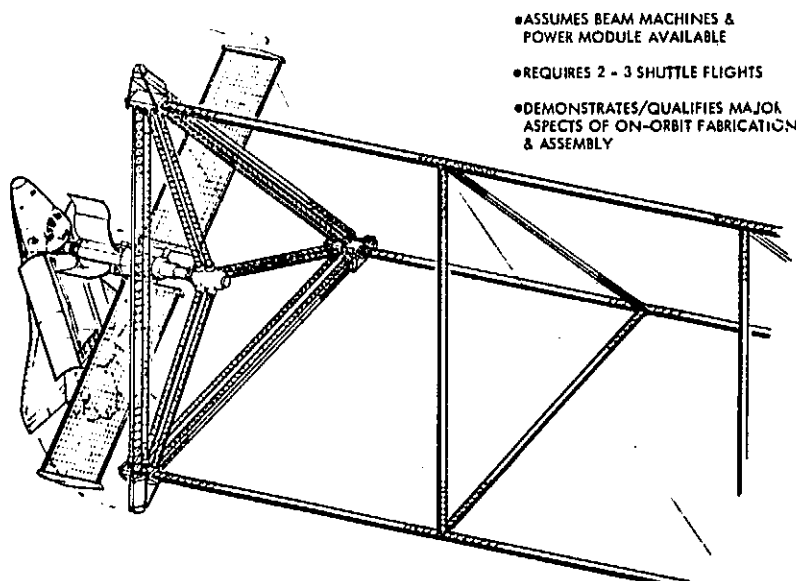
- ASSUMES BEAM MACHINE AVAILABLE
- SHUTTLE POWER SUFFICIENT FOR EXPERIMENT
- REQUIRES SHUTTLE/BAM BUILDER PECULIAR JIGS & FIXTURES
- DEMONSTRATES
 - ON-ORBIT FABRICATION
 - IN-SITU RESPONSE TO COMPRESSION & TORSION LOADS & DELTA TEMPERATURES
- SMALL SECTION OF BEAM ELEMENT RETURNED IN SHUTTLE FOR FAB QUALITY EVALUATION



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Figure 2.5-4. Shared Shuttle Sortie 2-m Tri-Beam Element Fab and Test

The second experiment would be the on-orbit fabrication and test of a full-scale tri-beam girder, as shown in Figure 2.5-5. This will require two or three dedicated Shuttle flights, and assumes availability of an auxiliary power module. This experiment demonstrates the use of six beam machines working concurrently, which is the basis of the Rockwell construction plan. The development of a construction module is charged against this task. The resulting tri-beam may be subjected to structural testing and then utilized for further development activity.



- ASSUMES BEAM MACHINES & POWER MODULE AVAILABLE
- REQUIRES 2 - 3 SHUTTLE FLIGHTS
- DEMONSTRATES/QUALIFIES MAJOR ASPECTS OF ON-ORBIT FABRICATION & ASSEMBLY

Figure 2.5-5. Full-Scale Tri-Beam Sortie Demo



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On-Orbit Antenna Structure Fabrication and Test. This would be the final structural test proposed for the SPS structural subsystem development effort. This task is the on-orbit Shuttle-assisted fabrication and assembly of an SPS microwave antenna structure. Approximately ten dedicated Shuttle flights and a full complement of construction equipment are required. This experiment will demonstrate and verify the major aspects of on-orbit construction results in the tension web/compression frame microwave antenna structure shown in Figure 2.5-6.

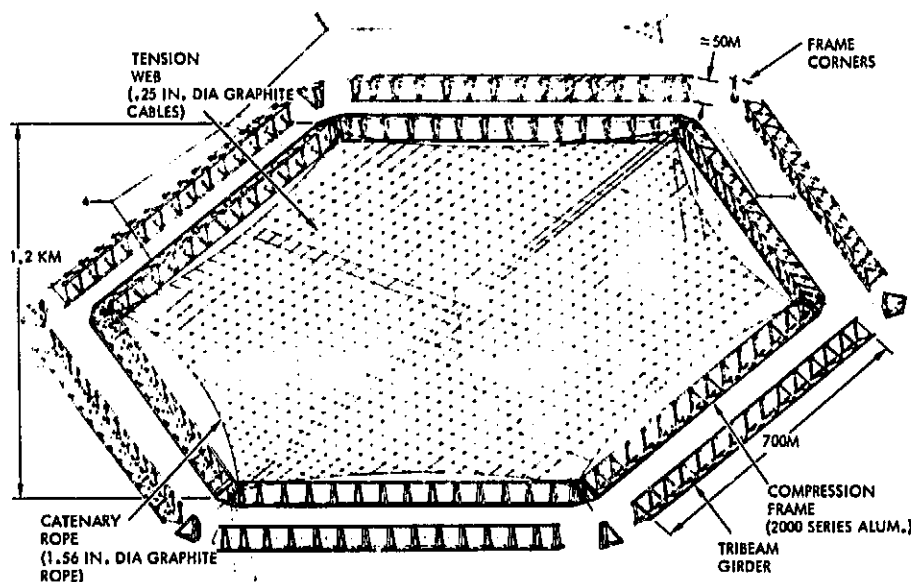


Figure 2.5-6. Tension Web/Compression Frame
Microwave Antenna Structure

2.6 GEOSAT MULTI-FUNCTION TEST SYSTEM

A multi-function GEOSAT, capable of Shuttle launch to LEO and electric self-propulsion during orbital transfer to geosynchronous altitude, would provide the principal SPS satellite effort during the technology verification phase. The proposed GEOSAT test system will support environmental testing of critical SPS components and subsystems, and will also operate in conjunction with the 1-km linear ground antenna array for far-field microwave phase control testing.

A preliminary conceptual sketch of the SPS GEOSAT system is shown in Figure 2.6-1. The SPS GEOSAT test system will include the following hardware test elements.

- *Beam-mapping subsatellite* - Used in conjunction with ground-to-geospace microwave phase control and beam quality tests.
- *Pilot beam transmitter module* - To provide retrodirective signal to ground 1-km line array.



- *MPTS Klystron-RCR component test module* - To conduct high-voltage plasma interaction tests and evaluate RFI characteristics.
- *Modular GaAs solar array elements* (≈ 100 kWe) - To conduct high-voltage testing and evaluate solar cell efficiency and degradation in geosync and during Van Allen Belt traverse.
- *High-voltage power distribution and slip ring subsystem elements* - To simulate end-to-end power chain efficiency and high-voltage plasma effects.

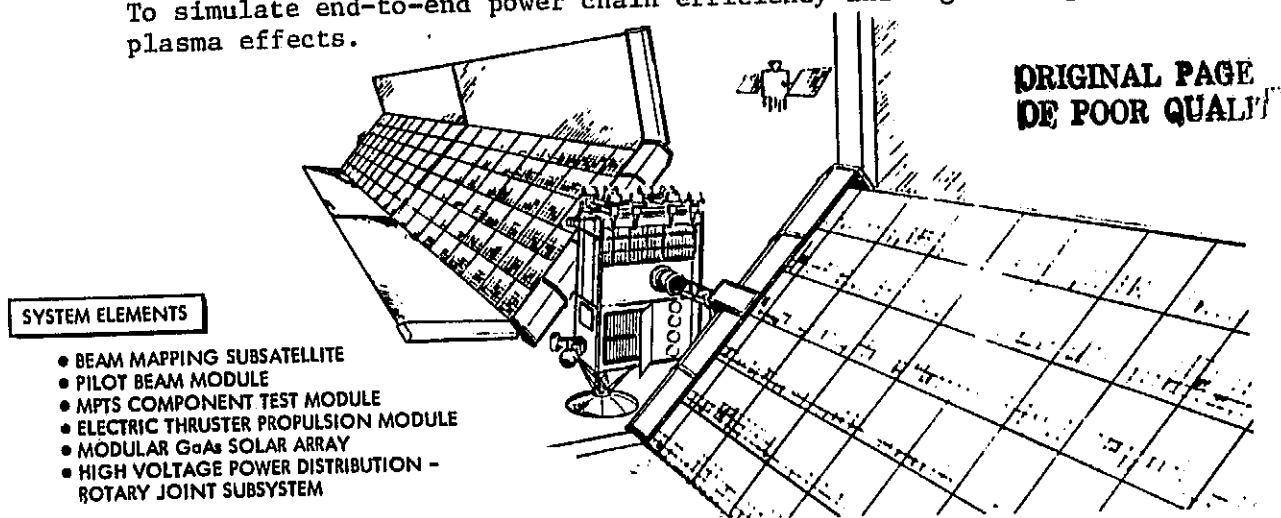


Figure 2.6-1. SPS GEOSAT System Elements

As described in Section 2.2 (Microwave Power Transmission System), the pilot-beam element of the GEOSAT system illuminates the ground antenna linear array where the beam is received by the line source retro-electronics which, in turn, phase the line source to return its beam to the GEOSAT. The beam is a fan beam since the line source aperture is a full-scale one kilometer in the east-west direction, but only one power module wide (≈ 1 m) in the north-south direction.

The beam-mapping GEOSAT piggyback subsystem operates in a free-flying mode and probes the beam pattern by controlled drifting in an east-west pattern.

Along with those orbital test functions related to MPTS ground-to-GEO testing, the GEOSAT EOTV will also be used as the test vehicle for verification of the solar array, power distribution, and control subsystems. This offers the opportunity to perform LEO tests from the Shuttle, orbit transfer radiation degradation evaluations of GaAlAs solar cells and reflectors, and long-duration operational tests at GEO. The GEO tests include long-duration operational tests of solar array, power conversion, distribution and control as a system supplying the multiple required voltages at the klystrons. The solar array design for EOTV is based on SPS performance requirement (~ 650 W/kg). This will provide the SPS with evaluation of solar collector structure/attitude control interactions and high-voltage array performance. An additional benefit from this approach is the flexibility of payload return to earth. Based on results of this evaluation, adequate data are expected to be available to



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enable program decisions to be made in 1987 relative to SPS operational status. GEOSAT power conversion and distribution test elements and subsystem characteristics are shown in Figure 2.6-2.

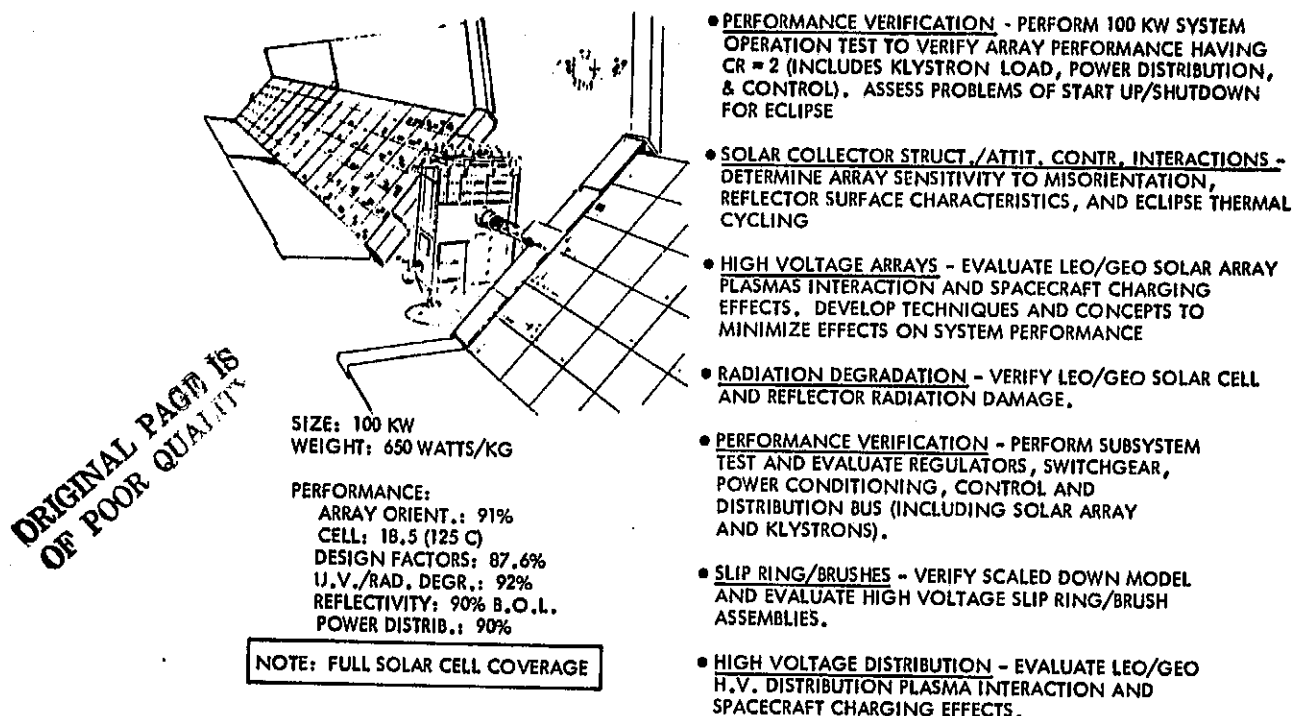


Figure 2.6-2. PC (GEOSAT) EOTV (1986-1988)

Further preliminary concept definition of this geosynchronous test system is required to establish preliminary system performance requirements and operational characteristics, including orbital mechanics, power, and Shuttle bay compatibility. An important concept development issue is whether to conceive a fully integrated SPS dedicated test article system, or to evolve a satellite system consisting of a standard multi-mission SEP's type vehicle bus with attached SPS payload modules for each of the critical subsystem test elements.

2.7 STS PROPULSION TECHNOLOGY

The development of SPS transportation support system elements is also a key element of the SPS verification plan. Development phasing of key STS system elements is summarized in Figure 2.7-1.

The basic assumption which essentially controls this development schedule is the 1987 go-ahead decision for SPS Phase C/D. The IOC of Shuttle growth at this time would significantly reduce launch vehicle costs (dollars per pound to orbit) in the post-1987 development phase. As presented earlier, the need for the GEOSAT gives focus to the near-term development of argon-ion electric thrusters and power processors. The schedule for the two-stage chemical OTV reflects the current engine development work being conducted for a Space Shuttle upper stage, thus the relatively short duration of the C/D phase for this system.

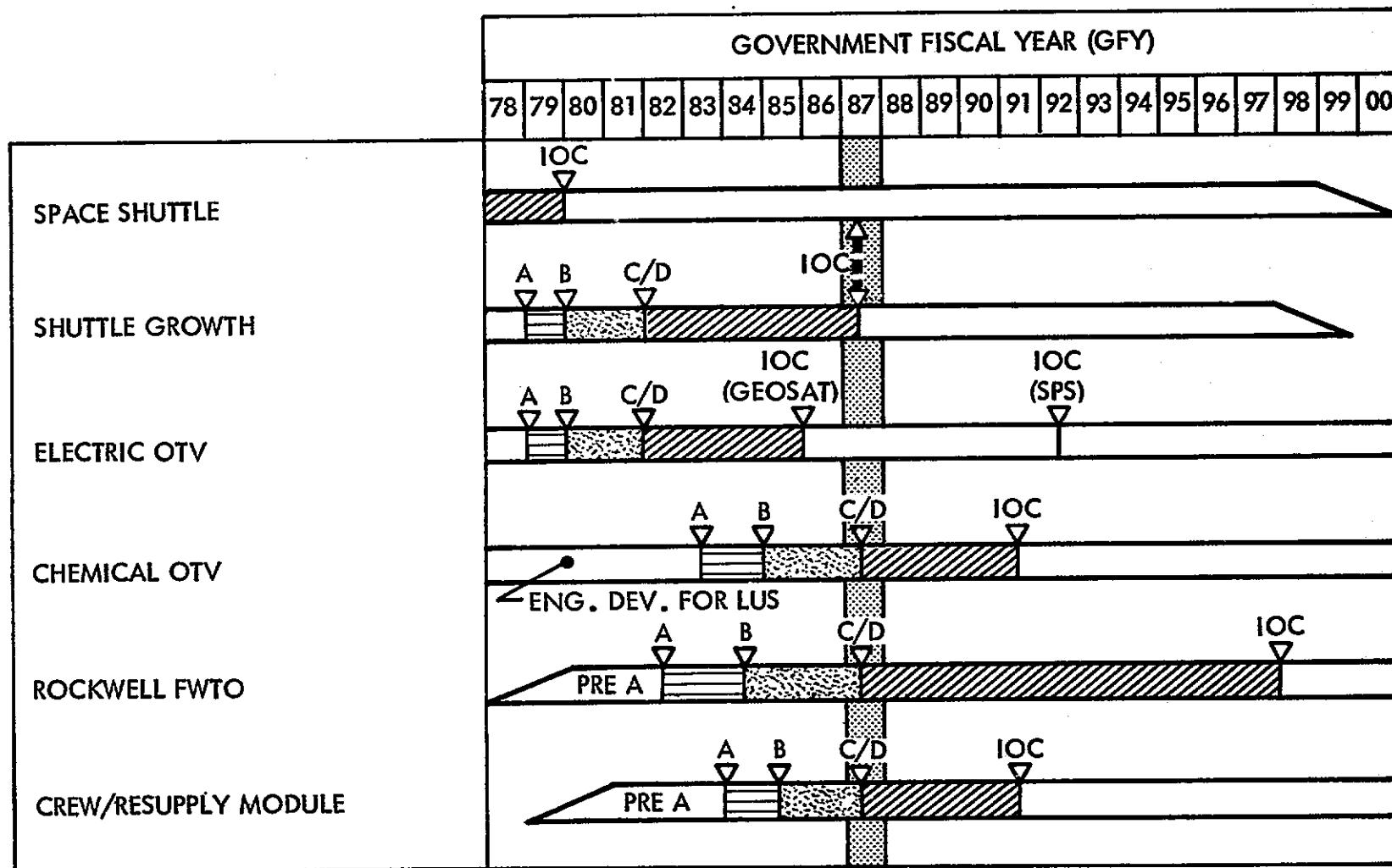
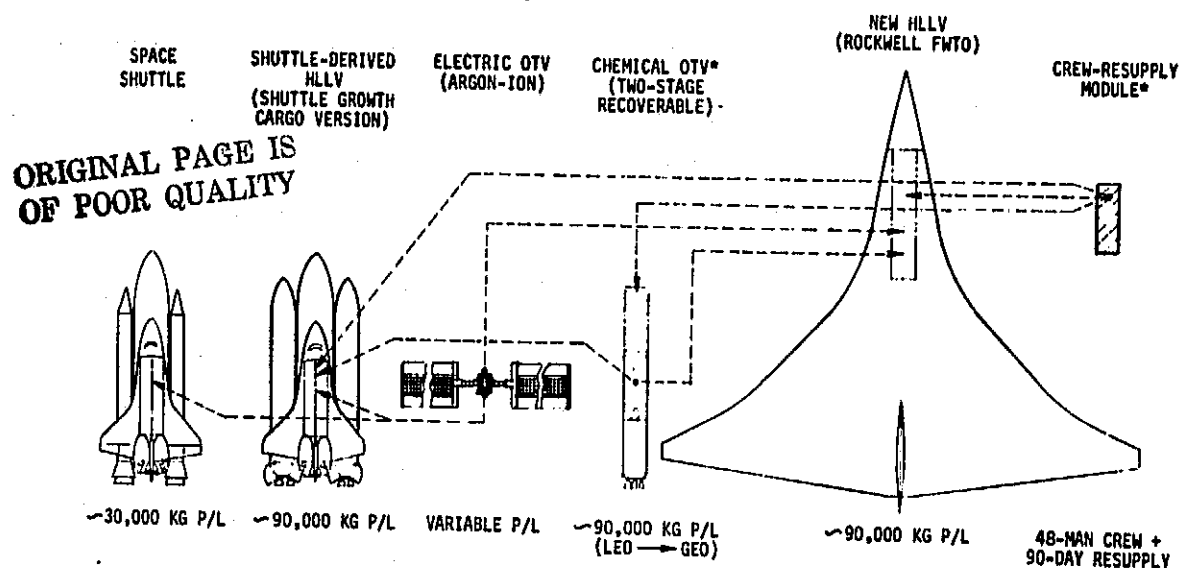


Figure 2.7-1. SPS Transportation Systems Development



Holding to a new HLLV Phase C/D ATP of GFY 1987 results in more than adequate time to fully assess the capabilities of any new concept which may primarily be dedicated to the SPS program.

In the evolution of mass transfer capability in support of the SPS development scenario, cargo bay modularity is an important parameter; this is illustrated in Figure 2.7-2.



*THE MASS OF EACH CHEMICAL OTV STAGE IS ~90,000 KG AND THE CREW-RESUPPLY MODULE UP MASS IS 37,000 KG

Figure 2.7-2. SPS Transportation Systems

SPS transportation system concepts are depicted approximately to scale along with their payload capabilities. These systems are based on cargo transfer effected via an independent electric OTV with subsequent satellite construction at GEO. It is noteworthy that payload mass and size compatibility is assured between launch vehicles, OTV's, and the crew/resupply module (CRM). The two-stage chemical OTV is used in the CRM, but can be employed for "priority" cargo if needed. The Rockwell FWTO returns the CRM to earth as well as expended OTV's for refurbishment and refueling.

A preliminary overview summary of proposed STS technology tasks is shown in Table 2.7-1, which indicates the major systems analytical and developmental efforts for the 1978-1988 era. The SRT requirements for Shuttle growth have been documented in detail in the final report of the Shuttle Growth Study (NAS8-32015). Tasks for the remaining SPS transportation systems are, for the most part, self-explanatory but have to be described at a higher level of definition at this time. Task scheduling and phasing are shown in Figure 2.7-3.

Table 2.7-1. SPS Transportation Systems Task Definition by Program Element

PROGRAM ELEMENT SPS TRANSPORTATION SYSTEM	EARLY ANALYSIS EXPLORATORY LAB EFFORT	GROUND TEST PROGRAM		SPACE TEST PROGRAM	
		COMPONENT DEVELOPMENT	INTEG GRD TESTING	SHUTTLE SHARED SORTIES	SHUTTLE DEDICATED SORTIES
		78-80	81-85	82-85	86-88
SHUTTLE GROWTH	• DESIGN DEFINITION STUDY • WATER IMPACT DYNAMICS COMPUTER MODELING • BOOSTER PARACHUTE DESIGN	• PPO FOAM TEST ARTICLE FAB • SUBSCALE VERIFICATION OF WATER IMPACT DYNAMICS COMPUTER MODEL	• PRESSURE, THERMAL & IMPACT TESTING OF PPO FOAM TEST ARTICLE • BOOSTER SUBSCALE AIRBORNE DROP TESTS	N/A	N/A
ELECTRIC OTV	• EOTV SYSTEM SIZING/OPTIMIZATION STUDY • ARGON-ION THRUSTER & POWER MODULE LABORATORY TESTING	• LARGE (100-150CM) THRUSTER/POWER PROCESSOR COMPONENT DEVELOPMENT • EOTV BREADBOARD TESTING	• THERMAL-VACUUM CHAMBER TESTS OF EOTV PROTOTYPE	• EOTV PROPULSION MODULE PROTOTYPE TEST	• EOTV PROPULSION SYSTEM FOR SPS GEOSAT (LAUNCH TO GEO)
CHEMICAL OTV (PRIORITY CARGO & PERSONNEL)	• COMMON-STAGE CHEMICAL OTV SIZING STUDY	• CHEMICAL OTV MONITORING/SELF-TESTING COMPUTER EQUIPMENT	• INTEGRATED PROPULSION SYSTEM TESTS	(POST-87 TESTING WITH SHUTTLE GROWTH SYSTEM)	
RI-FWTO	• SYSTEM CONCEPT FEASIBILITY STUDIES • ENGINE DESIGN STUDIES • COMPUTER TRAJECTORY SIMULATION PROGRAM	• TURBOFAN-RAMJET ENGINE COMPONENT DEVELOPMENT • WING/TANK/TPS STRUCTURAL FAB & TESTS	• WIND TUNNEL MODEL TESTING • INTEGRATED TURBOFAN-RAMJET TESTING (MODIFIED J-58, E.G.)	(NONE)	• SUBORBITAL HYPER-VELOCITY TEST ARTICLES (2)
CREW/RESUPPLY MODULE (LEO → GEO)	• CONCEPTUAL DESIGN STUDIES	• LIFE SUPPORT SUBSYSTEMS COMPONENTS DEVELOPMENT	• LSS PROTOTYPE TESTING	(POST-87 TESTING WITH SHUTTLE GROWTH SYSTEM)	

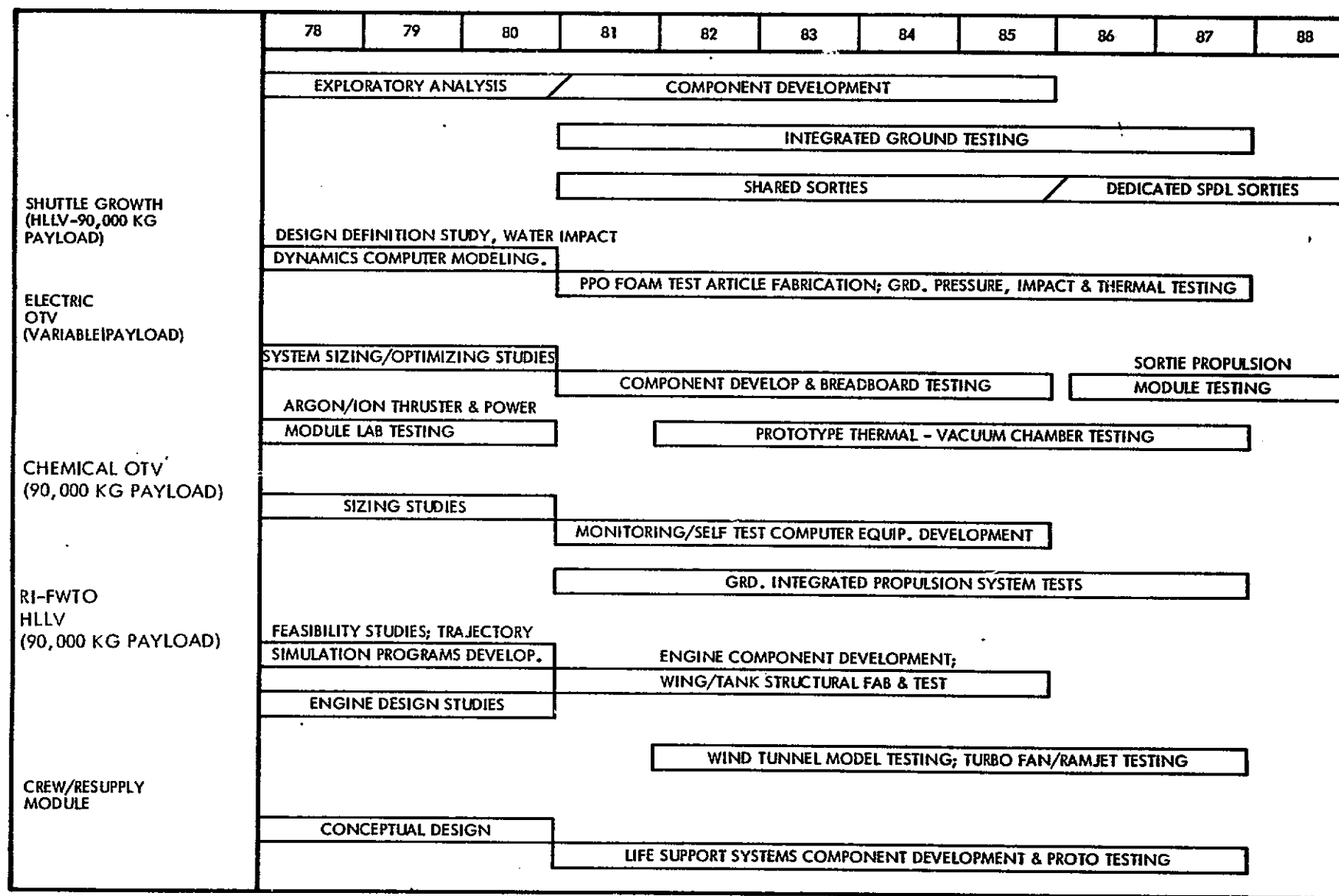


Figure 2.7-3. Task Scheduling and Phasing



2.8 TECHNOLOGY EXPERIMENTAL/VERIFICATION PROGRAM COST SUMMARY

Technology verification program cost estimates, at this point in SPS system concept definition, can only be considered as broad gauges of probable funding requirements subject to continuing review and assessment as the study effort narrows down system baseline definition and development planning options. Table 2.8-1 summarizes ROM funding estimates for the Option B development planning scenario.

Table 2.8-1. Experimental/Verification Program Costs

<u>Program Phase</u>	<u>ROM Cost</u>
• Experimental Research (1978-1982)	\$15-25 million
• Technology Verification (1981-1987)	\$2.5-3.5 billion
• Prototype Development and Demonstration (1988-1998)	\$25-35 billion

Subsystem and experimental task cost breakdowns for the early analysis experiment program and the technology verification program are summarized in Tables 2.8-2 and 2.8-3. A preliminary cost summary for STS supporting system technology development is presented in Table 2.8-4.

Table 2.8-2. Preliminary Cost Summary - Early Analysis (1980-1982)

<u>MPTS</u>	<u>\$K</u>	<u>STRUCTURES/ASSEMBLY</u>	<u>\$K</u>
✓ IONOSPHERIC HEATING EXPMTS	(4000)*	✓STRUCT. DESIGN CRITERIA & VERIF.	200
✓ GEOSAT CONCEPT DEFINITION	(250)*	✓MATERIALS DEVELOPMENT	400
✓ GRND TEST RANGE DEFINITION	250	✓NUMERICAL CHARACTERIZATION	500
✓ ANTENNA PATTERN CALCULATIONS	100	✓CONSTRUCTION EQUIP. DEVELOPMENT	500
✓ KLYSTRON/PWR TRANSISTOR DEF.	300	✓CONTROL SYST. CONCEPTS & REQMTS	500
✓ RCR CONCEPT EVALUATION	200	✓DEVELOPMENT & EVALUATION, ACS	
✓ GaAs DIODE CONCEPT EVALUATION	150	PROPULSION SYST. ANALYSIS	1000
TOTAL	1000	TOTAL	3100
*NON-ADD (REF. ONLY)			
<u>POWER CONVERSION</u>	<u>\$K</u>	<u>POWER DISTRIBUTION</u>	<u>\$K</u>
✓ GaAs SOLAR CELL ADV. DEVELOP.	1300	✓HIGH-VOLTAGE/CURRENT XMISSION	
✓ CVD FAB PROCESS SCALE-UP	1600	SIMULATION	450
✓ SOLAR CELL & REFLECTOR		✓SPACECRAFT CHARGING ANALYSIS	95
RADIATION TESTS	750	✓SLIP RING/BRUSHES MATERIALS	
✓ REFLECTOR PERFORMANCE TESTS	300	INVESTIGATION	120
✓ HIGH-VOLTAGE (40 kV) SOLAR CELL		✓FLAT CONDUCTOR JOINING PROCESSES	
STRING DESIGN	200	EXPERIMENT	60
TOTAL	4150	✓SUPERCONDUCT. CABLE INVEST.	125
		TOTAL	850

Table 2.8-3. Preliminary Cost Summary - SPS Technology Verification Phase (1981-1987)

COMPONENT DEVELOPMENT	RANGE - \$B	RANGE - \$B	
		0.750	1.000
✓MPTS	0.500 - 0.650		
✓POWER CONVERSION	0.025 - 0.050		
✓POWER DISTRIBUTION	0.125 - 0.150		
✓STRUCTURE/ASSEMBLY	0.100 - 0.150		
INTEGRATED GROUND TEST		0.750	1.300
✓GRTE	0.500 - 0.850		
✓POWER CONV/DIST	0.150 - 0.250		
✓STRUCTURE/ASSEMBLY	0.100 - 0.200		
SPACE TEST		1.000	1.200
✓SPS-GEOSAT	0.250 - 0.350		
✓SHARED SORTIES	0.100 - 0.125		
✓DEDICATED SORTIES	0.650 - 0.725		
✓TOTAL FORECAST		2.500	3.500

2-45

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Table 2.8-4. Preliminary Cost Summary - SPS Support System (1978-1987)

STS ELEMENTS	PROGRAM ELEMENTS	EARLY ANALYSIS 1978-1980	GROUND TEST (\$M)		SPACE TEST
			COMP. DEV. 1981-1987	INTEG. TEST 1982-1987	
SHUTTLE GROWTH*		2.500	7.500	10.000	-0-
✓ PPO FOAM REUSABILITY		0.400	1.000	2.500	
✓ WATER IMPACT DYN. MODELING		0.600	0.500		
✓ LANDING SYSTEM DROP TEST		1.500	6.000	7.500	
ROCKWELL FWT0		1.500	60.000	102.500	140.000
✓ CONCEPT FEASIBILITY STUDIES		1.500			
✓ TURBOFAN-RAMJET ENGINE COM- PONENT DEVELOPMENT			50.000		
✓ WING/TANK SECTION STRUCTURE FAB & TEST			10.000		
✓ WIND TUNNEL MODEL TESTING				2.500	
✓ INTEG TURBOFAN-RAMJET TESTING				100.000	
✓ SUBORBITAL HYPERVELOCITY TEST ARTICLE					140.000
ELECTRIC OTV		2.000	10.000	2.500	35.00
✓ ANAL & COMPONENT LAB TESTING		2.000			
✓ LARGE (≥ 100 CM) THRUSTER DEV.			5.000		
✓ BREADBOARD TESTING			5.000		
✓ THERMAL-VACUUM TESTS				2.500	
✓ PROPULSION MOD PROTOTYPE TESTS					35.000
CHEMICAL OTV		-0-	2.500	15.000	-0-
✓ MONITORING/SELF-TESTING COMPUTER EQUIPMENT			2.500		
✓ PROPULSION SYSTEM TEST				15.000	
TOTAL FORECAST		6.000	80.000	130.000	175.000
*NON-ADD & DDT&E COST = \$1.5 B (1977)			TOTAL	391.000	



3.0 SUPPORTING RESEARCH AND TECHNOLOGY

This section presents, in summary form, those early analysis/experimental research tasks required to provide the requisite proof of feasibility for critical issue technology elements of the SPS system. Establishment of firm designs, performance levels, development requirements, cost/efficiency trades, and system environmental acceptability all depend on early verification of the achievable characteristics of many critical subsystem components/elements.

The proposed supporting research and technology (SRT) tasks in this section are grouped by major subsystem technologies as listed below.

- Microwave Power Transmission Technology
- Power Conversion Technology
- Power Distribution Technology
- Structures Technology
- STS Propulsion Technology

Individual tasks within each subsystem technology area are presented in RIOP format including justification, objectives, approach, task schedules, and costs.

These proposed tasks reflect SPS concept definition design decisions at this point in time, and cannot be considered as all-inclusive. Subsequent point-design decisions and guidelines will dictate continuing reassessment and updating of this preliminary SPS SRT task plan.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TECHNOLOGY TITLE MICROWAVE POWER TRANSMISSION TECHNOLOGY

● TECHNICAL SUMMARY

The objective of this effort is to conduct critical early analyses and exploratory technology relating to microwave energy transmission key technical issue resolution and fundamental technical feasibility. The tasks in this plan address critical component definition issues relative to microwave power amplification and transmission, ground power rectification, and initial definition of microwave ground test range requirements and characteristics. Computer simulation modeling, experimental lab development and engineering model evaluation will be performed.

● TASK SUMMARY

<u>TITLE</u>	<u>FUNDING \$K</u>	
	<u>80</u>	<u>81</u>
1) Ground Test Range Definition	100	150
2) 50 kW Klystron Definition	200	
3) RCR Concept Evaluation	100	100
4) Antenna Pattern Calculation	100	
5) GaAs Diode Concept Evaluation	50	100
6) Power Transistor Definition	100	
	650	350

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE MPTS GROUND TEST RANGE DEFINITION

● JUSTIFICATION

A very large percentage of MPTS critical technical issues can be substantially resolved through a comprehensive, progressive microwave transmission ground development program. A more precise definition of required ground test range requirements and facilities is an essential prerequisite to initiation of MPTS subsystem development.

● TECHNICAL OBJECTIVES

To determine specific detailed verification test and performance requirements and test system concepts for ground to ground (near-field) and ground to geosynchronous orbit (far-field) verification testing of MPTS subsystem elements, including interface parameters and requirements for a geosat multi-function test system operating in conjunction with a 1 km ground linear array.

● APPROACH

Task sequence will be to establish sequential technical issue resolution requirements, define overall test system characteristics and conduct system concept definition studies for principal ground test elements. The following subtasks will be performed:

- a) Define MPTS critical technology verification resolution requirements as a parametric basis for proposed test system objectives.
- b) Describe overall sequential end-to-end MPTS system test characteristics including location, power requirements, instrumentation, etc.
- c) Develop preliminary design concept definition for 600 meter and 6 km ground to ground test ranges and a ground to geo 1 km linear array antenna installation.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE MPTS GROUND TEST RANGE DEFINITION

● MILESTONE SCHEDULE

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● FUNDING

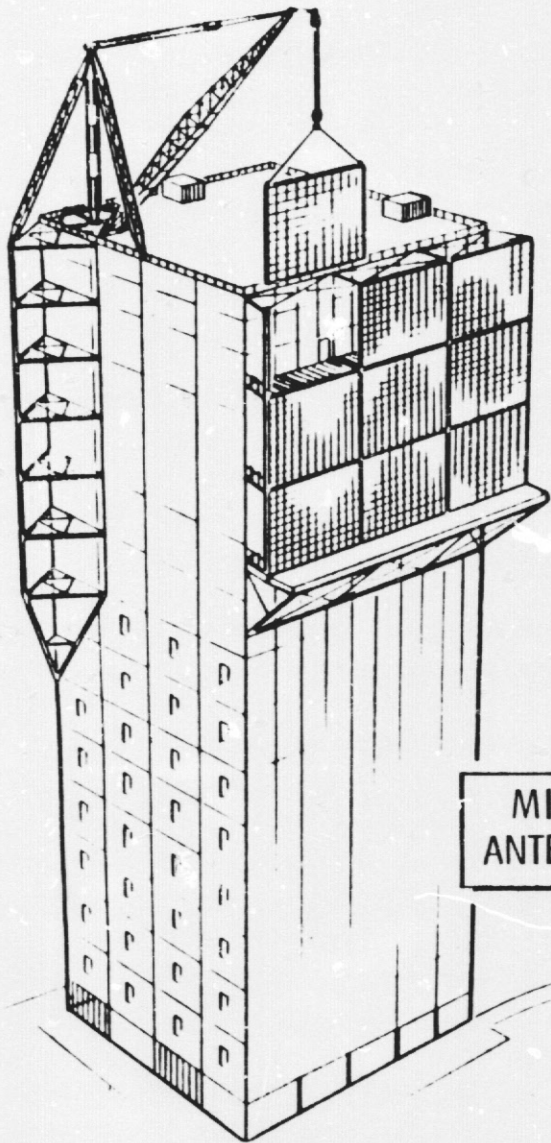
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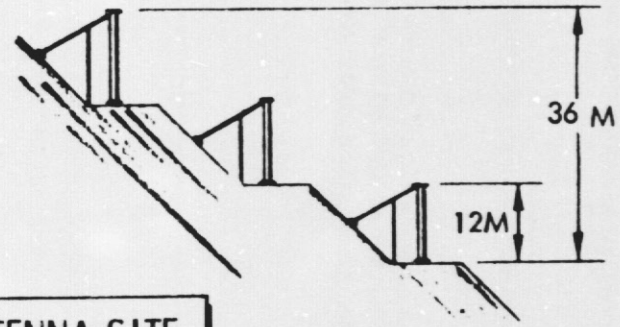
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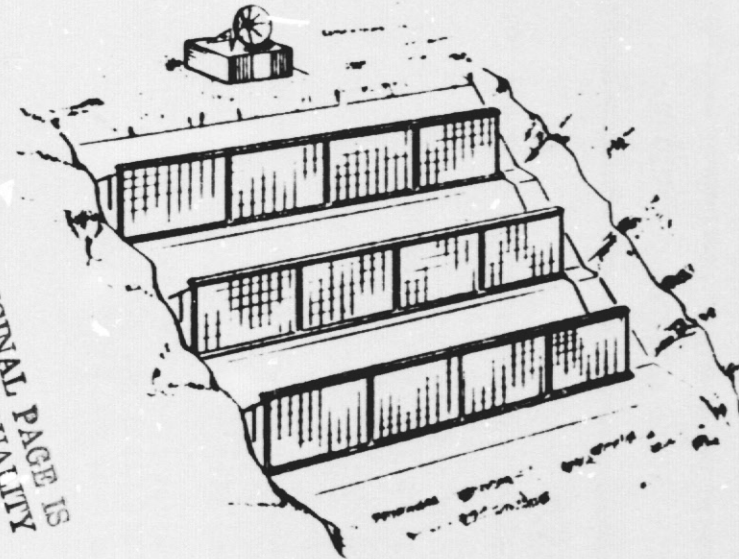


MICROWAVE
ANTENNA TOWER



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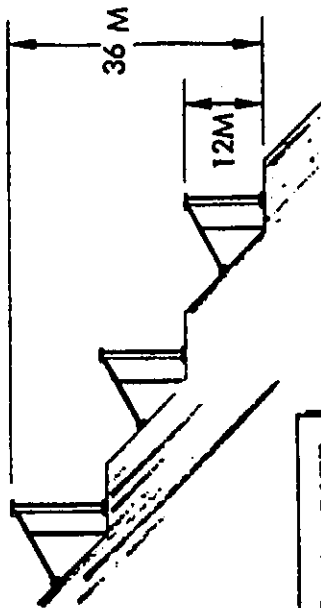
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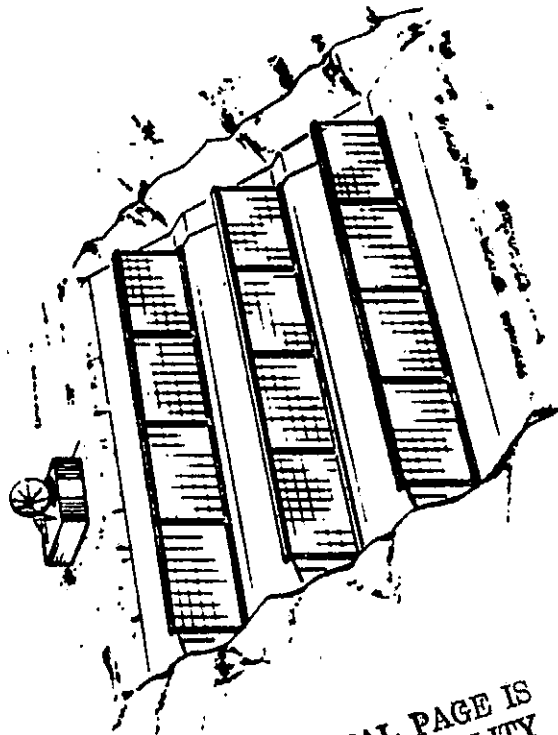
GROUND-TO-GROUND NEAR-FIELD MICROWAVE TEST RANGE



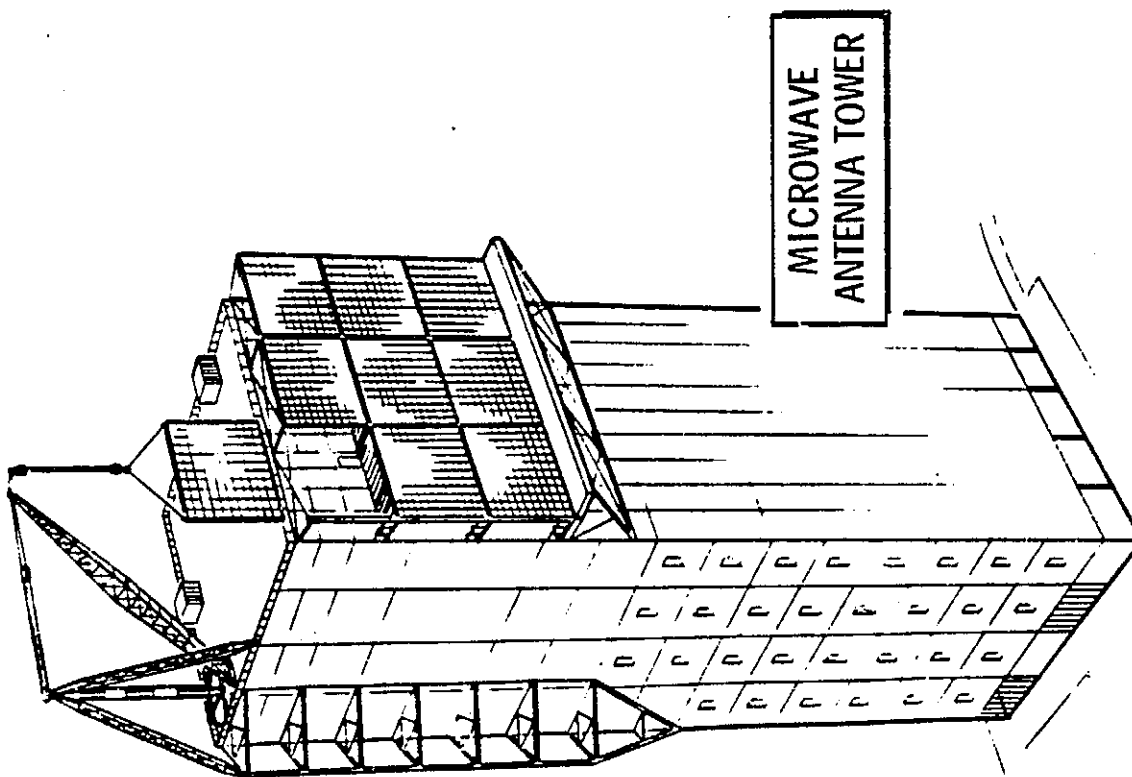
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MICROWAVE
ANTENNA TOWER

GROUND-TO-GROUND NEAR-FIELD MICROWAVE TEST RANGE

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE 50 KW KLYSTRON DEFINITION

● JUSTIFICATION

The high-power Klystron converter must be completely characterized and defined before MPTS design definition can be initiated. Klystron electrical definition requires application of the "floppy disc" digital electron-beam simulation program. Collector electron optics requires analogue simulation.

● TECHNICAL OBJECTIVES

Perform computational simulation in a computer-aided-design process to define an optimized SPS Klystron, generate initial design and assembly sequences and provide a basis for cost and performance prediction.

● APPROACH

1. Assemble and proof analogue and digital programs
2. Perform Klystron definition simulation optimization
3. Generate design drawings
4. Develop assembly flow scenario and instructions

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● **TASK TITLE** 50 KW KLYSTRON DEFINITION

● **MILESTONE SCHEDULE**

MILESTONES	CY 1980												CY 1981												CY 1982												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
● ANALOG - DIGITAL PROGRAM ASSEMBLY & ANALYSIS				—	▽																																
● GENERATE KLYSTRON DESIGN OPTIMIZATION					—			▽																													
● GENERATE DESIGN DWGS								—		▽																											
● DEVELOP ASSEMBLY FLOW & PROCEDURES										—		▽																									
● FAB & TEST PROTO LAB MODEL *														—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

NOTES:

*Proto Klystron lab model fab & test projected as
Component Development Task

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● **FUNDING**

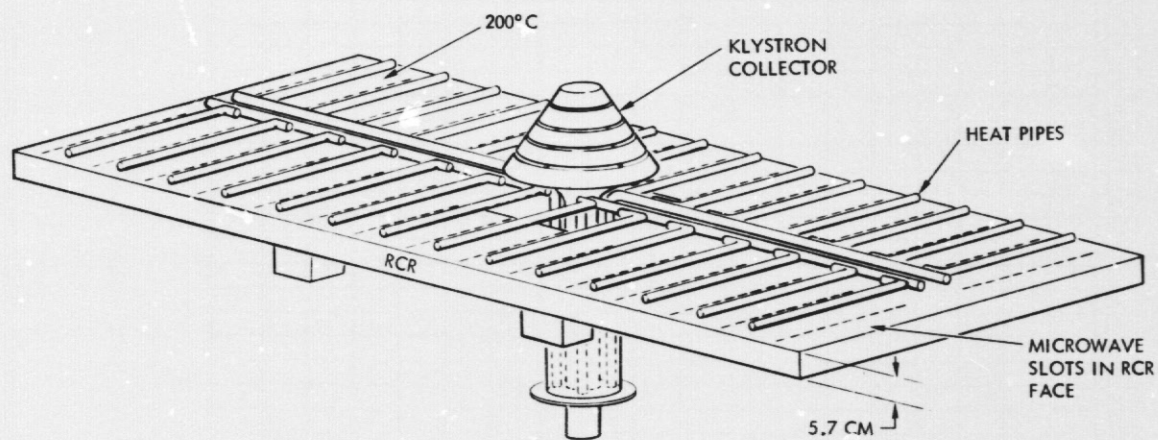
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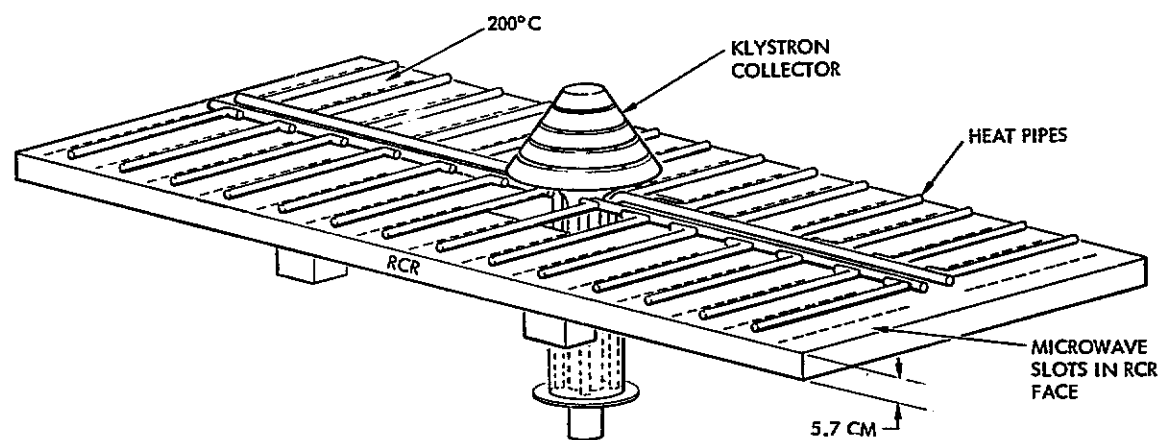
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RADIATING FACE OF POWER MODULE

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RADIATING FACE OF POWER MODULE

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SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE RCR CONCEPT EVALUATION

● JUSTIFICATION

An integrated microwave - radiator/power converter module must be characterized and developed in detail as a necessary prerequisite to point-design MPTS performance, mass and cost determinations.

● TECHNICAL OBJECTIVES

Perform development of a point-design RCR/Klystron module with required pattern, adequate cooling and an economical manufacturing process. Ohmic cost will be considered a major parameter.

● APPROACH

Resonant Cavity Resonator configurations of various characteristics will be designed and evaluated. Variants will include feeder placement, introduction of the klystron well, addition of heat-pipe grid, and use of choke joints for assembly. Experimental model will be tested in a space simulator for cooling performance, multipaction, temperature distribution and other performance characteristics.

SP3 SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE RCR CONCEPT EVALUATION

● MILESTONE SCHEDULE

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● RESOURCE REQUIREMENTS

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- **FUNDING**

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\$100 K

● FACILITIES

YES

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE MPTS ANTENNA PATTERN CALCULATION

● JUSTIFICATION

Microwave beam computed patterns taking into account all deviations from ideal behavior are required for projected point-design MPTS antenna concepts prior to developmental hardware testing. Later ground to geo line array pattern measurements must correlate well with antenna pattern modeling to verify antenna design adequacy.

● TECHNICAL OBJECTIVES

Assemble a specialized computer program for calculation of MPTS antenna array and line source simulation pattern behavior.

● APPROACH

1. Construct an optimized computer program using as subprograms, existing programs for computing line and planar array patterns from the array excitation.
2. The main program will identify excitation functions by calling subprograms which generate perturbations of the ideal excitations generated in the MAINGO.
3. Evaluate and utilize the following subprograms:

- | | | |
|----------|----------|----------|
| ● MAINGO | ● WEIGHT | ● RECTNA |
| ● LOCATE | ● XFORM1 | ● PRTPLT |
| ● RETRO | ● XFORM2 | ● CRTPLT |
| ● STEER | ● VALUES | ● TBLPLT |

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE MPTS ANTENNA PATTERN CALCULATION

● MILESTONE SCHEDULE

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NOTES:

● RESOURCE REQUIREMENTS

FY 80

FY 81

FY 82

- FUNDING
- FACILITIES

\$100 K
(COMPUTATION)

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE GaAs DIODE CONCEPT EVALUATION

● JUSTIFICATION

Diode and corollary rectifier circuits must be characterized and developed as a prerequisite to SPS rectenna configuration definition and cost and performance determination.

● TECHNICAL OBJECTIVES

Develop diode and rectifier circuit software programs, evolve optimum diode and circuit design and evolve efficient fabrication processes. Inasmuch as problems in defining GaAs parameters are the same as for the GaAs transistor program task, perform this task in parallel.

● APPROACH

The development of the diode CAD program can be a simplification of the Waterloo transistor program, BIPOLE. As in the transistor case either WATAND or REPAC can be used for the CAD rectifier circuit program. Test diodes are then made and compared with the computer program results. GaAs parameters and structure data is modified according to lab results then new designs are run. This will continue until an optimum design is obtained.

Rectenna performance will then be calculated in light of the optimum design parameters.

Finally large-scale manufacture methods will be projected from the laboratory fab processes and volume production costs estimated.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE GaAs DIODE CONCEPT EVALUATION

● MILESTONE SCHEDULE

ORIGINAL PAGE
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[illegible]

NOTES:

● RESOURCE REQUIREMENTS

FY 80

FY 81

FY 82

- **FUNDING**

\$50 K

\$100 K

● FACILITIES

(COMPUTATION)

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE POWER TRANSISTOR PRELIMINARY DEFINITION

● JUSTIFICATION

A preliminary concept definition and performance evaluation of three transistor power converters must be performed as a basis for the power module point design decision by 1981 prior to component development and verification.

● TECHNICAL OBJECTIVES

Evaluate the performance and S-O-A manufacturing potential for advanced power transistor development for application to MPTS power amplification.

● APPROACH

Task will consist of an iterative process of data acquisition on GaAs parameters, calculation of optimized transistor performance and evaluation of production potential.

The task sequence includes the following:

- a) Collection of preliminary GaAs parametric data
- b) CAD design of transistor using variation of Waterloo program - BIPOLE
- c) CAD design of amplifier circuits using either Waterloo - WATAND or RI - REPAC
- d) Fabrication and test evaluation of transistor and amplifier performance
- e) Refinement of GaAs data and efficiency projection

C-2

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE POWER TRANSISTOR PRELIMINARY DEFINITION

● MILESTONE SCHEDULE

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[illegible]

NOTES:

● RESOURCE REQUIREMENTS

FY 80

FY 81

FY 82

- FUNDING
- FACILITIES

\$100 K

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TECHNOLOGY TITLE

SPS POWER CONVERSION TECHNOLOGY

● TECHNICAL SUMMARY

The objective of this program is to identify and develop the component and subsystem technologies for an advanced photovoltaic conversion subsystem to support the SPS design and trade off studies. The GaAlAs photovoltaic subsystem has the potential of low weight, increased performance, higher resistance to ionized radiation levels and the ability to operate with concentrators with minimum loss in performance compared to Si cells and it should actively be developed. Determination of the state-of-the-art, analyses, computer modeling, design and trade off studies, and fabrication, test and development of the major components will be conducted in the proposed program.

● TASK SUMMARY

1. GaAs Solar Cell Advanced Development - The objective of this program is to develop a GaAs cell for space applications with a minimum efficiency of 20% at AMO and 28°C. The development of a 20% GaAs cell is required for a practical design of a Solar Power Satellite for the post 1995 time period. High efficiency, high production capabilities associated with low cost is required. Analysis, design, fabrication and testing are required to develop the GaAs cell.
2. CVD Fabrication Process Scale-up - The objective of this program is to continue and improve the CVD fabrication process in order to obtain increase yields and high efficiency GaAlAs cells. Research and development, testing and optimum cell designs have to be obtained for establishing a strong technology base to support the SPS design.
3. Solar Cell & Reflector Radiation Tests - The objective of this program is to characterize the advanced GaAlAs cells and reflectors for an on orbit 30 year radiation environment. Various cell designs and reflector membrane specimens will be fabricated and tested to various radiation energy levels and fluxes in laboratory test chambers. The test results will be analyzed and used to project the component performance for the SPS mission.
4. Reflector Performance Tests - The objective of this program is to survey the industry and perform tests for determining the surface and optical properties of reflective membranes of 12.5 μm (0.5 mil) or less in thickness. Concentration ratios of approximately 7 to 8 can be used with GaAlAs cells before an active thermal control system would be required. With the higher concentration ratio the design complexity increases and the SPS sizing then becomes very sensitive to misorientation angles with respect to the sun. Preliminary analysis have indicated that concentration ratios of approximately 2 to 5 are attractive for the SPS for a passive cooled solar array design.
5. High Voltage (40 kV) Solar Cell String Design - High voltages of 40 kV to 50 kV are essential for the reduction of power distribution weight and to minimize the power distribution losses on the SPS. The high voltage arrays also permits the direct coupling of the power conversion subsystem to the microwave antenna. This eliminates the necessity of high weight power conditioning equipment to step up the array voltages to be compatible with the 40 kV klystron input.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE GaAs SOLAR CELL ADVANCE DEVELOPMENT

- JUSTIFICATION A solar power satellite capable of delivering 5 GW of power to the utility on the ground will require an array output of approximately 9.76 GW at the end of life. Utilizing the GaAs type cell will result in a solar blanket area of approximately 30.6 km² which is considerably less area than if Si type cells were used. The GaAs cell offers the potential of high efficiency, low weight, reduced deployment area, high efficiency at elevated operating temperatures which permits concentrators to be used for obtaining concentration ratios up to 5 to 7, and the GaAs cell is more resistant to the space radiation environment compared to Si cells.

● TECHNICAL OBJECTIVES

The objective of this effort is to develop advance GaAlAs cells and to demonstrate their performance and reliability for space applications.

● APPROACH

Analyze, design and fabricate prototype cells. Determine characteristics, materials, and tolerances that effect the performance of cells and upgrade to improve power output and voltage rating. Measure α and ϵ of cell, covers and cell stack. Determine effects and assess impact of reducing junction thickness on cell performance, mfg cost and gallium availability. Investigate and develop improved cell interconnects for large production rate. Assess optimum cell size based on cost, production array, blanket fabrication techniques and stowage and deployment constraints.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE GaAlAs CELL ADVANCE DEVELOPMENT

● MILESTONE SCHEDULE

ORIGINAL PAGE
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MILESTONES	CY 1980												CY 1981												CY 1982												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
1. ANALYZE AND EVALUATE CELL PARAMETERS FOR INCREASED EFFICIENCY																																					
2. DESIGN CELL AND DETERMINE BEST FABRICATION METHODS																																					
3. FABRICATE CELL OF SPACE TYPE QUALITY																																					
4. PERFORM TESTS																																					
5. REDESIGN CELLS TO INCORPORATE TEST IMPROVEMENTS																																					
6. FABRICATE NEW CELLS AND PERFORM TESTS																																					
7. DOCUMENTATION																																					

NOTES:

● RESOURCE REQUIREMENTS

FY 80

FY 81

FY 82

● FUNDING

\$300 K

\$400 K

\$600 K

● FACILITIES

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE CVD FABRICATION PROCESS SCALE-UP

● JUSTIFICATION

A solar power satellite capable of delivering 5 GW of power to the utility on the ground will require an array output of approximately 9.76 GW at the end of life. One of the major components that have a significant impact on the SPS weight and cost is the design and performance of the GaAlAs solar cell. The development and refinement of the CVD fabrication process for the manufacture of GaAlAs cells has the potential for high production rates for the cells. The CVD process has to be developed in order to obtain high performance cells with high manufacturing yields and low unit cost which are required to make the SPS economically viable with advanced power plants.

● TECHNICAL OBJECTIVES

Analyze the manufacturing processes and design improved techniques and equipment that will result in the manufacture of high efficiency GaAlAs cells. Fabricate and test cells to demonstrate the improved CVD processes.

● APPROACH

The process variables, tolerances and the equipment size have to be defined. Establish production yields, process times, mfg costs and plant size which are necessary to determine production rates. Define facility requirements and cell costs. Analyze the gallium cycle for recycling, minimizing losses and reduction in gallium content for cell performance.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● **TASK TITLE** CVD FABRICATION PROCESS SCALE-UP

● **MILESTONE SCHEDULE**

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MILESTONES	CY 1980												CY 1981												CY 1982											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1. DEFINE PROCESS VARIABLES	_____																																			
2. DETERMINE EQUIPMENT SIZE AND PRODUCTION													_____																							
3. DEFINE FACILITY REQUIREMENTS													_____																							
4. INVESTIGATE THE GALLIUM PROCESS FOR RECOVERY AND RECYCLING																									_____											
5. DEMONSTRATE CVD PROCESS CONTROL AND TECHNOLOGY																									_____											
6. DOCUMENT RESULTS																									_____											

NOTES:

● **RESOURCE REQUIREMENTS**

- FUNDING
- FACILITIES

FY 80

\$300 K

-

FY 81

\$500 K

TBD

FY 82

\$800 K

TBD

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE SOLAR CELL & REFLECTOR RADIATION TESTS

- JUSTIFICATION The radiation effects on solar cells and reflectors has been estimated to result in degradations of as high as 20 to 30% for the SPS type mission. The high degradation factors results in increased sizing of the SPS with additional weight and cost penalties. There is some preliminary data available that indicates these factors may be too high. A well balanced test program is required to obtain actual cell and reflector performance data for the radiation environment in order to design and determine the size and cost of the SPS with a higher confidence level.

● TECHNICAL OBJECTIVES

Conduct detailed analyses of the cell structure to determine methods and designs to increase the radiation resistance. Fabricate and test cells and reflective membranes to the radiation environment and correlate test data with analytically results.

● APPROACH

Perform analyses and computer modeling of the devices to determine the performance for the radiation environment. Conduct radiation tests on space type cells and reflector specimens and correlate and compare data with math models. Develop and evaluate techniques to minimize radiation degradation such as thermal annealing of cells, increased thickness of reflector coating, development of increased radiation harden solar cells.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE SOLAR CELL & REFLECTOR RADIATION TESTS

● MILESTONE SCHEDULE

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MILESTONES	CY 1980												CY 1981												CY 1982												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
1. PERFORM ANALYSES																																					
2. WRITE COMPUTER PROGRAMS FOR RADIATION EFFECTS ON COMPONENTS																																					
3. SELECT SAMPLES FOR TESTING																																					
4. CONDUCT RADIATION TESTS OF FLIGHT TYPE CELL & REFLECTOR MEMBRANES																																					
5. UPDATE AND COMPARE COMPUTER MODEL WITH TEST RESULTS																																					
6. DETERMINE TECHNOLOGY IMPROVE- MENTS FOR RADIATION HARDENING OF DEVICES																																					
7. DOCUMENTATION																																					

NOTES:

● RESOURCE REQUIREMENTS

- FUNDING
- FACILITIES

FY 80

FY 81

FY 82

\$200 K

\$250 K

\$300 K

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE REFLECTOR PERFORMANCE TESTS

- JUSTIFICATION One technique to reduce the weight and cost of a SPS photovoltaic power conversion subsystem is to employ reflective membranes to concentrate the solar energy on the cells. The reflective membranes increase the solar energy falling on the cells and therefore the high cost solar cells are partially replaced by the utilization of low weight, low cost reflective membranes. The surface reflectivity and optical properties of thin reflective membranes under tension in the space environment is practically non-existent. These design data are critical for the design of a solar concentrator photovoltaic power conversion subsystem.

● TECHNICAL OBJECTIVES

The objective of this effort is to determine the state-of-the-art of thin film reflective membranes for space missions and assess techniques for developing manufacturing methods for thinner gages and improved performance. Perform tests of the membranes to determine the surface and optical properties for use in the design of the SPS concentrator configurations.

● APPROACH

Contact vendors and coating firms to determine the state-of-the-art of reflective thin film technology. Determine reflectivity values for thin film membranes based on coating thickness, surface properties, membrane tension, attachment devices, and manufacturing and deployment techniques. Determine tolerance variations on coatings and membrane thicknesses. Determine impact of membrane size and attachment device on reflectivity. Assess value of protective coatings and selective filters on reflector performance.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● **TASK TITLE** REFLECTOR PERFORMANCE TESTS

● **MILESTONE SCHEDULE**

ORIGINAL PAGE 12
OF POOR QUALITY

MILESTONES	CY 1980												CY 1981												CY 1982												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
1. DETERMINE STATE-OF-THE-ART																																					
2. INVESTIGATE AND DETERMINE REFLECTIVITIES AND OPTICAL PROPERTIES OF MEMBRANES																																					
3. FABRICATE TEST ARTICLES & TEST																																					
4. EVALUATE AND DEFINE STRUCTURAL PROBLEMS AND PROMISING ATTACHMENT DEVICES																																					
5. DETERMINE OPTIMUM MEMBRANE SIZE																																					
6. DOCUMENT PROGRAM RESULTS																																					

NOTES:

● **RESOURCE REQUIREMENTS**

FY 80

FY 81

FY 82

● FUNDING

\$100 K

\$150 K

\$50 K

● FACILITIES

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE HIGH VOLTAGE (40 KV) SOLAR CELL STRING DESIGN

● JUSTIFICATION

High voltage solar arrays will be required to obtain a practical SPS design configuration. High voltage arrays have to be designed, developed and tested for space use. High voltage analytical and design data for solar arrays is non-existent for space applications. A design and development effort is required in order to obtain the basic technology data for use in the design and sizing studies for the SPS.

● TECHNICAL OBJECTIVES

Investigate the cell blanket design as to interconnections, dielectric strength, plasma leakage effects, and spacecraft charging isolation. Assess series parallel arrangements, effects of cell shadowing and variation in solar intensity on the array and voltage form.

● APPROACH

Analyze and define potential problems of the baseline high voltage array. Configure, test and evaluate high voltage solar cell strings on typical blanket and structure configuration. Determine dielectric characteristics of array string as a function of voltage, materials of construction, and simulated on orbit environmental effects. Analyze and reduce test data for use in the design of high voltage solar arrays.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● **TASK TITLE** HIGH VOLTAGE (40 KV) SOLAR CELL STRING

● **MILESTONE SCHEDULE**

ORIGINAL PAGE 1
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MILESTONES	CY 1980												CY 1981												CY 1982												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
1. PERFORM ANALYSIS	█	█	█	█																																	
2. DESIGN & FABRICATE BASIC COMPONENTS FOR TEST						█	█	█	█	█	█	█																									
3. CONDUCT COMPONENT TESTS AND EVALUATE RESULTS											█	█	█	█	█	█	█																				
4. DESIGN & FABRICATE ARRAY STRING FOR HIGH VOLTAGE TESTING																█	█	█	█	█	█	█	█														
5. CONDUCT TESTS OF ARRAY																									█	█	█	█	█	█	█	█	█				
6. DEFINE ON ORBIT TEST PROGRAM																																			█	█	
7. DOCUMENTATION																																				█	█

NOTES:

● **RESOURCE REQUIREMENTS**

	FY 80	FY 81	FY 82
● FUNDING	\$50 K	\$50 K	\$100 K
● FACILITIES		TBD	TBD

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TECHNOLOGY TITLE SPS POWER DISTRIBUTION TECHNOLOGY

● TECHNICAL SUMMARY

The primary objective of the PDS early analysis is to develop mathematical models of the overall PDS for evaluating load variation, spacecraft charging and transient effects upon the PDS. The analysis will also indicate whether EMI filtering would be required and the best possible location of these filters. In addition, in depth analysis will be performed to determine whether superconductivity is cost effective for SPS application and how it could be best utilized for power distribution systems.

The second objective is to evaluate various materials for use in slip-rings and brushes, including various joining techniques for flat conductors.

● TASK SUMMARY

	<u>\$K</u>
● High Voltage/Current Transmission Simulation	450
● Spacecraft Charging Analysis	95
● Slip-Ring/Brushes Material Investigation	120
● Flat Conductor Joining Processes Experiment	60
● Superconduct. Cable Invest.	<u>125</u>
	\$850K

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE HIGH-VOLTAGE/CURRENT TRANSMISSION SIMULATION

● JUSTIFICATION

With an orbiting power station, it is essential that load variations, transients and faults be determined so that proper control requirements can be established to insure continuous power transmittal to the ground station. It therefore, becomes essential that mathematical models be developed for computer simulation to investigate load variations, transients and fault detection schemes. The simulation would then aid in locating critical areas where sensors could be located so that proper corrective action could be taken.

● TECHNICAL OBJECTIVES

The objectives of the high voltage/current transmission simulation are as follows:

1. Develop mathematical models of components and loads.
2. Develop overall PDS mathematic model.
3. Investigate load variation effects.
4. Investigate transient effects.
5. Investigate fault detection (perform short circuit analysis).
6. Investigate EMI effects and where filtering should be employed.

● APPROACH

This project will be divided into 4 separate phases. The first phase will be to identify and enumerate the engineering problems which must be solved to establish the requirements and outputs of the simulation. The second phase consist of building the mathematical models for the simulator and to perform a baseline configuration run. The results will be reviewed and updated where necessary. In case of update, a rerun of the baseline will be performed. The third phase consists of the actual study phase of PDS, presentation of the solutions, and recommendations of changes as well as additions. The last phase consists of updating the models to the latest configuration and rerunning phase 3 to insure that the corrections made satisfies the requirements.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE HIGH-VOLTAGE/CURRENT TRANSMISSION SIMULATION

● MILESTONE SCHEDULE

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NOTES:

● RESOURCE REQUIREMENTS

FY 80

FY 81

FY 82

● FUNDING	\$K
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150

200

100

- FACILITIES

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE SPACECRAFT CHARGING ANALYSIS

● JUSTIFICATION

In previous spacecraft vehicles, it has been found that under certain environmental conditions spacecraft charge affected various electronic functions. Some of these phenomena have been investigated and reported. Since the SPS is required to transmit continuous power from the satellite to the ground, it is apparent that a spacecraft charge model be developed for determining spacing charge effects on the PDS and subsystems.

● TECHNICAL OBJECTIVES

1. Review existing spacecraft charge math models and determine how they could be implemented.
2. Develop spacecraft charging mathematical model for the SPS.
3. Perform coordination with simulation engineers for incorporating the spacecraft charge mathematical model into the overall PDS simulation model.

● APPROACH

This project will be divided into three phases. The first phase consists of a review of existing spacecraft simulation models to determine whether they could be utilized in the overall simulation model or whether new models would have to be developed for the SPS configuration. The second phase consists of developing a suitable mathematical model to be used in conjunction with the PDS overall mathematical model. After model has been completed, simulation will be made to confirm accuracy of model. The last phase consists of interfacing with simulation engineers for incorporating the model into the overall PDS simulation model and also participate in the simulation evaluation.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE SPACECRAFT CHARGING ANALYSIS

● MILESTONE SCHEDULE

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NOTES:

● RESOURCE REQUIREMENTS

FY 80

FY 81

FY 82

● FUNDING \$K

95

- FACILITIES

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

► TASK TITLE SLIP-RING/BRUSH MATERIAL INVESTIGATION

● JUSTIFICATION

Transfer of large amounts of power to high voltages and currents through slip rings has never been performed in space. Test and performance data of high power slip rings for space is critical to the successful design and operation of slip rings for the SPS.

● TECHNICAL OBJECTIVES

The objectives of the study consist of:

1. Analyze slip ring design concepts and determine potential materials to use for the slip rings and brushes.
2. Establish prototype model sizes, design components and fabricate for testing.
3. Perform laboratory test to determine electrical, mechanical and thermal characteristics of the slip ring and brush assembly.

● APPROACH

1. Review design concepts of on orbit slip ring brush assemblies. Determine state-of-the-art of the technology and determine electrical, mechanical and thermal characteristics and performance of the design.
2. Discuss high voltage - high current slip ring requirements with vendors. Voltage drop, friction factors, wear rate, arcing, current density, brush pressure, and temperature effects are critical to the design of the slip ring brush assembly for long life and high performance.
3. Review SPS requirements and design prototype slip ring and brushes for testing.
4. Perform laboratory testing of prototype components and correlate test data with analytical design results.
5. Document results of the study and test programs.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE SLIP RING/BRUSH MATERIAL INVESTIGATION

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[illegible]

NOTES:

● RESOURCE REQUIREMENTS

	FY 80	FY 81	FY 82
1. <u>Operating Expenses</u>	1,000	1,000	1,000
2. <u>Capital Expenses</u>	1,000	1,000	1,000
3. <u>Other Expenses</u>	1,000	1,000	1,000
4. <u>Revenue</u>	1,000	1,000	1,000
5. <u>Net Income</u>	1,000	1,000	1,000
6. <u>Other Income</u>	1,000	1,000	1,000
7. <u>Other Expenses</u>	1,000	1,000	1,000
8. <u>Net Income</u>	1,000	1,000	1,000
9. <u>Other Income</u>	1,000	1,000	1,000
10. <u>Other Expenses</u>	1,000	1,000	1,000
11. <u>Net Income</u>	1,000	1,000	1,000
12. <u>Other Income</u>	1,000	1,000	1,000
13. <u>Other Expenses</u>	1,000	1,000	1,000
14. <u>Net Income</u>	1,000	1,000	1,000
15. <u>Other Income</u>	1,000	1,000	1,000
16. <u>Other Expenses</u>	1,000	1,000	1,000
17. <u>Net Income</u>	1,000	1,000	1,000
18. <u>Other Income</u>	1,000	1,000	1,000
19. <u>Other Expenses</u>	1,000	1,000	1,000
20. <u>Net Income</u>	1,000	1,000	1,000
21. <u>Other Income</u>	1,000	1,000	1,000
22. <u>Other Expenses</u>	1,000	1,000	1,000
23. <u>Net Income</u>	1,000	1,000	1,000
24. <u>Other Income</u>	1,000	1,000	1,000
25. <u>Other Expenses</u>	1,000	1,000	1,000
26. <u>Net Income</u>	1,000	1,000	1,000
27. <u>Other Income</u>	1,000	1,000	1,000
28. <u>Other Expenses</u>	1,000	1,000	1,000
29. <u>Net Income</u>	1,000	1,000	1,000
30. <u>Other Income</u>	1,000	1,000	1,000
31. <u>Other Expenses</u>	1,000	1,000	1,000
32. <u>Net Income</u>	1,000	1,000	1,000
33. <u>Other Income</u>	1,000	1,000	1,000
34. <u>Other Expenses</u>	1,000	1,000	1,000
35. <u>Net Income</u>	1,000	1,000	1,000
36. <u>Other Income</u>	1,000	1,000	1,000
37. <u>Other Expenses</u>	1,000	1,000	1,000
38. <u>Net Income</u>	1,000	1,000	1,000
39. <u>Other Income</u>	1,000	1,000	1,000
40. <u>Other Expenses</u>	1,000	1,000	1,000
41. <u>Net Income</u>	1,000	1,000	1,000
42. <u>Other Income</u>	1,000	1,000	1,000
43. <u>Other Expenses</u>	1,000	1,000	1,000
44. <u>Net Income</u>	1,000	1,000	1,000
45. <u>Other Income</u>	1,000	1,000	1,000
46. <u>Other Expenses</u>	1,000	1,000	1,000
47. <u>Net Income</u>	1,000	1,000	1,000
48. <u>Other Income</u>	1,000	1,000	1,000
49. <u>Other Expenses</u>	1,000	1,000	1,000
50. <u>Net Income</u>	1,000	1,000	1,000
51. <u>Other Income</u>	1,000	1,000	1,000
52. <u>Other Expenses</u>	1,000	1,000	1,000
53. <u>Net Income</u>	1,000	1,000	1,000
54. <u>Other Income</u>	1,000	1,000	1,000
55. <u>Other Expenses</u>	1,000	1,000	1,000
56. <u>Net Income</u>	1,000	1,000	1,000
57. <u>Other Income</u>	1,000	1,000	1,000
58. <u>Other Expenses</u>	1,000	1,000	1,000
59. <u>Net Income</u>	1,000	1,000	1,000
60. <u>Other Income</u>	1,000	1,000	1,000
61. <u>Other Expenses</u>	1,000	1,000	1,000
62. <u>Net Income</u>	1,000	1,000	1,000
63. <u>Other Income</u>	1,000	1,000	1,000
64. <u>Other Expenses</u>	1,000	1,000	1,000
65. <u>Net Income</u>	1,000	1,000	1,000
66. <u>Other Income</u>	1,000	1,000	1,000
67. <u>Other Expenses</u>	1,000	1,000	1,000
68. <u>Net Income</u>	1,000	1,000	1,000
69. <u>Other Income</u>	1,000	1,000	1,000
70. <u>Other Expenses</u>	1,000	1,000	1,000
71. <u>Net Income</u>	1,000	1,000	1,000
72. <u>Other Income</u>	1,000	1,000	1,000
73. <u>Other Expenses</u> </			

FY 81

FY 82

● FUNDING \$K

- FACILITIES

120

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE FLAT CONDUCTORS JOINING PROCESSES EXPERIMENT

● JUSTIFICATION

In SPS power distribution systems, flat conductors are preferred because they exhibit better heat dissipating qualities than round conductors. However, because of the length of these conductors, they appear hard to handle, therefore sectionalization is a necessity. The joining of these sections could alter the characteristics of the conductors, therefore it becomes important to investigate various joining processes to determine which will produce the optimum joint.

● TECHNICAL OBJECTIVES

The objectives of the study are:

1. Determine most feasible joining process.
2. Determine electrical and thermal characteristics.
3. Determine mechanical characteristics and strength of the joint.

● APPROACH

1. Review existing flat conductor cable joining concepts. Establish SPS cable sizes and determine number of joints that may be needed.
2. Evaluate the various joining techniques such as conductive adhesives, mechanical clamping and/or weldments for potential use on the SPS.
3. Design prototype joint for potential application to the SPS and fabricate.
4. Conduct tests to determine electrical and mechanical performance and strength. Assess ease of on orbit assembly and reliability of joint.
5. Document the results of the study and test program.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE FLAT CONDUCTORS JOINING PROCESSES EXPERIMENT

● MILESTONE SCHEDULE

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NOTES:

● RESOURCE REQUIREMENTS

FY 80

FY 81

FY 82

● FUNDING \$K

60

● FACILITIES

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE SUPERCONDUCTING POWER CABLE INVESTIGATION

● JUSTIFICATION

With orbiting satellites it is very important that numerous schemes be investigated for possible reduction of the overall power and distribution weight so that transportation cost could be minimized. One such scheme is the utilization of superconductive cables. A cursory analysis indicated that with such technique a reduction of approximately 1/2 in conductor weight could possibly be achieved.

● TECHNICAL OBJECTIVES

The objectives of the study would be to:

1. Develop exact mathematical physics of the superconductive state to determine design and performance parameters for high current conductor elements.
2. Analyze liquid and vapor helium thermal transfer configuration.
3. Design the cryogenic refrigeration subsystem and transport cooling loop superconductive conditions.
4. Investigate a control system for maintaining a 9° Kelvin state at the conductor site.

● APPROACH

1. Investigate and analyze the superconducting cables. Calculate heat leaks, operating temperatures, and cable sizes as a function of current carrying capacity, conductor length and materials of construction. Determine feasible and theoretical critical temperatures, and safety requirements.
2. Based on the preliminary cooling capacity requirements, investigate refrigeration concepts and machinery and size the system. Determine volume, weight, coefficient of performance, and system capacity. Establish radiator size and integrate with SPS configuration.
3. Evaluate control requirements for cryogenic and superconducting subsystems.
4. Document study results.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE SUPERCONDUCTING POWER CABLE INVESTIGATION

● MILESTONE SCHEDULE

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[illegible]

NOTES:

● RESOURCE REQUIREMENTS

	FY 80	FY 81	FY 82
1. PERSONNEL			
2. EQUIPMENT			
3. MATERIALS			
4. OTHER			

● FUNDING \$K

FY 80	FY 81	FY 82
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FY 81

FY 82

- FACILITIES

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TECHNOLOGY TITLE SPS STRUCTURES TECHNOLOGY

● TECHNICAL SUMMARY

The objective of this experimental research is to develop technology associated with specific aspects of the structural subsystem of an SPS (Solar Power System). Optimum structural element shapes will be developed based on design, analysis and test data. Advanced composite material systems will be selected for SPS structures, applications and mechanical properties of those systems will be developed. Mathematical simulations of SPS configurations will be generated and subjected to simulated operational environments to determine "as designed" structural integrity including operational stress levels and satellite distortions. SPS structure construction scenarios will be generated, construction equipment defined and conceptually designed, and a plan generated for the ground and on-orbit technology development of this equipment. Attitude and figure control technology and ACS propulsion system research is also included in this effort.

● TASK SUMMARY

	<u>\$K</u>
Structural Design Criteria and Verification	200
Materials Development	400
Numerical Characterization	500
Construction Equipment Development	500
Attitude and Figure Control Techniques for Flexible Large Structures	500
ACS Electric Propulsion Development	<u>1000</u>
Total	3100

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE STRUCTURAL DESIGN CRITERIA & VERIFICATION

● JUSTIFICATION

At the heart of an SPS (Satellite Power System) large space structure is the beam element fabricated on-orbit by a beam builder or machine. This beam element consists of ultra thin-walled lightweight cap sections, transverse struts, & tension braces combined to form an open triangular shape from either aluminum or composite materials. Optimizing these caps & struts for maximum specific strength (i.e., allowable operating stress level, σ , divided by the mass per unit length) dictates that cutouts be incorporated in their design. The allowable operating stress, σ , is a function of both general buckling & local crippling of the selected material as influenced by the operating temperature & eccentricities caused by temperature gradients through the section, manufacturing irregularities & joint efficiencies. Optimized specific strength can only be determined by design variations supported by detailed mathematical simulation coupled, finally, with hardware testing.

● TECHNICAL OBJECTIVES

Develop optimized cap & transverse strut configurations compatible with:

- Materials
- Beam Builder Concepts
- Force & Torque Levels
- Ground Processing Techniques

● APPROACH

This task will consist of three (3) phases conducted serially. The first phase will be directed toward - establishing the design requirements & criteria for a beam element based on existing study results from all government & industry sources.

The second phase will be an iterative design & analysis process. This will result in one or more potentially optimum designs for both the longitudinal cap section & the transverse strut including joining details.

The third phase will consist of the fab & test of the design/s resulting from Phase 2.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE

STRUCTURAL DESIGN CRITERIA AND VERIFICATION

● MILESTONE SCHEDULE

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NOTES:

● RESOURCE REQUIREMENTS

FY 80

FY 81

FY 82

- FUNDING

150 K

50 K

- FACILITIES

YES

YES

NO

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE MATERIALS DEVELOPMENT

● JUSTIFICATION Advanced composite material systems have a high potential for extensive application to SPS and other large space structures. Their high specific strength, low coefficient of thermal expansion (α) and the low energy required to form and weld or bond them together make them extremely attractive from a technical point of view. Operational thermal environments ($>300^{\circ}\text{F}$) that would eliminate aluminum alloy as a structural material would also eliminate state-of-the-art composite systems such as graphite/epoxy and dictate the use of an advanced high temperature system that uses a matrix material such as polyimide based resin. The requirement for on-orbit fabrication may dictate a composite system that is classified as a thermoplastic rather than the thermosetting systems used for aerospace structures today. To apply these advanced systems to a detailed SPS structure design will require that a complete set of mechanical properties data be generated to supply the designer and structural analyst with material design allowables.

● TECHNICAL OBJECTIVES

Develop a design data guide for candidate advanced composite material systems with the greatest potential for application to an SPS structural subsystem. This data guide will be similar in concept and level of depth to "Metallic Materials & Elements for Aerospace Vehicle Structures (MIL-HDBK-5B)".

● APPROACH

This program will consist of three (3) phases conducted serially. The first phase will be the development of material requirements and criteria based on results of existing Government and aerospace contractor SPS systems studies. This will consist primarily of determining the environment the materials will be subjected to throughout the mission from launch to end of life.

Phase II will consist of material screening tests resulting in the selection of advanced composite material systems with the highest potential for application in the environmental regime established in phase I.

Phase III will be the conduct of extensive mechanical properties testing to develop 3 σ design allowables consistent with standard ASTM methods. The result will be a design data guide for use in detailed SPS structure design.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE MATERIALS DEVELOPMENT

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● MILESTONE SCHEDULE

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PHASE I - REQMTS & CRITERIA																																				
PHASE II - SCREENING TESTS																																				
PHASE III - MECHANICAL PROPER- TIES TESTING																																				

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE NUMERICAL CHARACTERIZATION

● JUSTIFICATION A major contributor to the success of the SPS system is its structural integrity during assembly and operation. The SPS being very large, very complex, and an extremely lightweight and minimum-gauge structure will demand accurate analytical methods to determine loads, stresses, and dynamic behavior. Such a large and complex system must employ the computer using computer methods to determine such items as the dynamic behavior of the structure for control and the responses from the control system; the induced loads from antenna motion; the effects of rapid thermal transients; deflection of the system for pointing accuracy; member sizes for required system stiffnesses; and other related structural behavior. To use the computer programs will require a math model of the system. The size and complexity of the system will require that the model be made in steps and built up from the subelements to the overall system, and particularly for the use in the dynamic analysis that some degrees of freedom be omitted, yet accurately represent the final structure. The antenna structure, particularly the netting structure, must be modeled separately, since the stiffness of support structure and the stiffness of the webbing are orders of magnitude apart, causing ill-conditioned matrices within the computer programs. Once the structural models are complete and in use, they must be updated and refined based on test data from both earth and space test programs which deal with difficult predictable factors as joint stiffness, crippling stresses, shape factors for loading and buckling of very long thin sections, eccentricities due to manufacturing and assembly, and changes in structural properties due to local thermal variations.

● TECHNICAL OBJECTIVES

- Develop subelement and component models for SPS structure for use in loads, stress, thermal, and dynamic analyses.
- Verify analytic structural behavior of SPS subelement and components with test results.
- Refine and update the computer structural model due to both analytic and test results.
- Use of the structural model as an effective design aid in the design and analysis of a lightweight, long-life, and an efficient structural system for the SPS and similar large space structures.

● APPROACH This task will be accomplished in four overlaying phases. Phase I will consist of the modeling of the basic subelement structural members to determine their stiffness due to their lightweighted (cutouts) design configuration. In addition, Phase I will include a study to determine which major computer program, Nastran or Stardyne, should be used. Two problems exist in the Nastran program. The first is a method to handle the pretension X-tie bracings when the bracing goes into compression. The second problem is the inability of Nastran to handle beam elements with running loading and stress recovery thereof.

Phase II, using the results of Phase I, will consist of the modeling of the major components using substructuring methods. The antenna structure (webbing and equipment support by the webbing) will be treated as a separate unit, and not included in the overall



structural system due to its very low stiffness compared to the rest of the structure. However, the effects of the antenna webbing and mass will be included in the overall system model. Both stress and dynamic models will be prepared.

Phase III will be the analytical phase. In this phase, using the stress and dynamic models, various loading and thermal profile cases will be run to check out the structural behavior of the system, both for stress and dynamics. The results will be iterated to determine control properties, removal of undesirable dynamic characteristics, the preliminary sizing of the members, determination of deflections of the structure during assembly and operating life, and the behavior of the structure under rapid changes in thermal environments.

Phase IV will overlap Phase III, using the results of tests which will determine the effects of joint connections, material properties under long-life conditions, crippling and buckling behavior of long extra-thin sections, and other related data; the computer program models will be altered and updated. In addition, the computer program models will be used to predict the behavior of test articles. After testing, the computer results and test results will be compared, with test results being incorporated into the models.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE NUMERICAL CHARACTERIZATION

● MILESTONE SCHEDULE

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NOTES:

● RESOURCE REQUIREMENTS

FY 80	FY 81	FY 82
\$100 K	\$200 K	\$200 K

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE CONSTRUCTION EQUIPMENT DEVELOPMENT

- JUSTIFICATION Because of its massive size, the success of an SPS (Satellite Power System) is dependent on the ability to accomplish a major portion of the construction activity on-orbit. On-orbit construction will necessarily require the early definition of construction equipment so that their early technology verification development activity can be defined and accomplished in a time frame compatible with other phases of the program. The beam builder is an example of on-orbit construction equipment. Almost every SPS study conducted by NASA and the aerospace industry has identified this piece of equipment as being necessary and requiring early development. The identification of other construction equipments, which may be even more complex than the beam builder must be accomplished in the near term future. To do this, an SPS configuration must be selected and subjected to a detailed construction scenario that will identify this equipment.

● TECHNICAL OBJECTIVES

Identification and preliminary design of SPS on-orbit construction equipment along with a plan for the ground and on-orbit technology development activity.

● APPROACH

This project will consist of three overlaying phases. Phase I will consist of the development of an end-to-end construction scenario starting with payload modules as delivered to the construction site and ending with the completed construction of the satellite structure and operational equipment.

Phase II will consist of the identification and preliminary design of construction equipment necessary to support the scenario developed in phase I.

Phase III will consist of the preparation of a detailed ground and on-orbit technology development plan for each piece of equipment identified in phase II.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● **TASK TITLE**

CONSTRUCTION EQUIPMENT DEVELOPMENT

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● MILESTONE SCHEDULE

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NOTES:

● RESOURCE REQUIREMENTS

FY 80

FY 81

FY 82

● FUNDING

\$200 K

\$200 K

\$1.00 K

● FACILITIES

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE ATTITUDE & FIGURE CONTROL TECHNIQUES FOR FLEXIBLE LARGE STRUCTURE

● **JUSTIFICATION** Traditionally the achievement of satisfactory control system/structural dynamic performance and stability has been achieved through the use of analytical and ground testing techniques to confirm modeling assumptions and uncertainties. With the extremely large, lightweight and flexible SPS structures full-scale dynamic testing is precluded. Hence, greater reliance must be placed on analytical techniques and sub-scale model testing to minimize expensive dynamic flight testing requirements. The different nature of the SPS structure warrants an investigation to define preferred dynamic modeling techniques and requirements for new modeling developments.

Figure Control - The requirements for figure control increase rapidly as a function of the concentration ratio (CR) of the solar collector. Higher CR's for photovoltaic collectors are desirable to minimize the cost of solar cell blankets. The introduction of bending sensors and electromechanical activators are the typical approach to figure control. New concepts such as a semi-passive "thermally activated expansion joint" concept offers promise as a low cost approach for SPS. Simple design techniques to minimize thermal bending also warrant investigation.

Attitude Control - For SPS new modeling and analytical tool developments are required to:

1. More accurately represent the flexibility of this class of structure.
2. Incorporate the dominant disturbances into the structural bending such as the gravity-gradient and the thermal bending excitation which can be the dominant control system excitation.
3. To facilitate the application of the new developments in modern control theory which are appropriate to the control of large flexible spacecraft.

● TECHNICAL OBJECTIVES

Figure Control - Define preferred structural concepts, passive design criteria to minimize structural distortion, and rationale for locating structural actuators. Define the relative merits of new unique figure control actuators and compare with contemporary electromechanical actuators. Define the preferred approaches for SPS.

Attitude Control - Define structural dynamic models for control system analysis that accurately represent SPS structural concepts; develop automated computer tools for control system analysis; and define preferred control software techniques to minimize undesirable dynamic interaction and flight test requirements to confirm the structural modeling.

● APPROACH

Figure Control - Define passive structural techniques to minimize thermal deformation and alignment techniques to minimize assembly misalignments. Define preferred locations for structural actuators, their requirements and alignment accuracies achievable. Investigate the design and performance achievable with new figure control actuator concepts such as the semi-passive "thermally controlled expansion joint." Define the preferred structure and figure concepts for SPS.

Attitude Control - Investigate the requirements for new structural dynamics modeling techniques and preferred approaches including the new disturbance models appropriate to SPS (gravity-gradient and thermal bending disturbances). Develop automated control system/structural dynamics analysis programs appropriate for these higher order systems. Investigate the application of modern control theory to minimize adverse structural dynamic interaction. Define the requirements for simple technology verification flight tests to confirm the modeling.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● **TASK TITLE** ATTITUDE & FIGURE CONTROL TECHNIQUES FOR FLEXIBLE
LARGE STRUCTURE

● **MILESTONE SCHEDULE**

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FIGURE CONTROL:																																						
● PREFERRED STRUCTURAL CONCEPT DEFINED & MODELED																																						
● PASSIVE TECHNIQUES INVESTIGATED																																						
● NEW ACTUATOR CONCEPTS INVESTIGATED, PERF. DEFINED																																						
● PREFERRED CONCEPTS SELECTED FOR SPS																																						
● DOCUMENTATION																																						
ATTITUDE CONTROL																																						
● STRUCTURAL DYNAMICS MODELING TECHNIQUES DEFINED																																						
● DISTURBANCE MODELING																																						
● PROGRAM DEVELOPMENT																																						
● ADVANCED CONTROL TECHNIQUES INVESTIGATED																																						
● PREFERRED SPS TECHNIQUES SELECTED																																						
● DOCUMENTATION																																						

NOTES:

● **RESOURCE REQUIREMENTS**

		FY 80	FY 81	FY 82
● FUNDING	Figure Control	100 K	125 K	65 K
	Attitude Control	75 K	100 K	35 K
● FACILITIES				

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE SA-6 ELECTRIC PROPULSION DEVELOPMENT

- JUSTIFICATION The '76 & '77 SPS study effort clearly established the desirability of high performance ($I_{sp} \approx 13,000$ sec.), long life, low cost electric propulsion for use in the SPS Attitude Control & Stationkeeping Subsystem (ACSS) and for the Electric Orbit Transfer Vehicle (EOTV).

Performance: The high performance electric propulsion for the EOTV was found to result in very substantial cost savings relative to a chemical OTV. For the SPS spacecraft the stationkeeping & attitude control functions were found to require high performance propulsion in order to prevent very large propellant resupply costs over the satellite lifetime.

Thruster Life: The currently estimated argon ion thruster lifetime of 5000 operating hours will result in large cost penalties for thruster replacement and/or refurbishment. Techniques to extend the lifetime of the thruster grids so as to minimize the overall cost (initial plus servicing) should be pursued.

(Check against EOTV Task)

Thruster Power Processing: Traditional electric thruster power processing electronics are quite massive and expensive. Techniques to utilize relatively raw power from the solar arrays and simpler control electronics to satisfy the thrusting requirements of the SPS spacecraft application require further investigation in order to define reliable, low cost power processing techniques equipment.

Cryogenic Propellant Storage: The storage of the argon propellant as a cryogen (rather than as a gas) will appreciably reduce tank mass and transportation costs for propellant delivery. The cryogenic propellant storage systems require further design analysis to define preferred design concepts.

● TECHNICAL OBJECTIVES

1. Define thruster design parameters, servicing requirements, power processing techniques and propellant storage design techniques to minimize the overall electric propulsion subsystem costs (hardware plus propellant resupply costs) for the EOTV & the SPS satellite RCS.
2. Confirm the performance & lifetime characteristics of the electric thrusters with ground based testing.
3. Develop a flight demonstration thruster for flight verification of performance and lifetimes.

● APPROACH

1. Perform mission requirements analyses and cost optimization studies to define the most cost effect thruster subsystem design parameters.
2. Perform preliminary and detailed thruster designs for ground and flight verification tests.
3. Perform ground and flight tests to confirm the thruster performance and lifetime characteristics.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● **TASK TITLE** SA-6 ELECTRIC PROPULSION DEVELOPMENT

● **MILESTONE SCHEDULE**

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MISSION REQUIREMENTS ANALYSIS	—————▽																																			
COST OPTIMIZATION ANALYSIS	—————▽																																			
PRELIM. DESIGN ANALYSIS	—————▽																																			
DETAILED DESIGN ANALYSIS													—————▽																							
LAB TEST COMPONENTS COMPLETE																									—————▽											
LAB TESTING COMPLETE																									—————▽											
FLIGHT TEST UNIT COMPLETE																									—————▽											
FLIGHT TEST COMPLETE																									—————→ DEC. '85											

NOTES:

● **RESOURCE REQUIREMENTS**

FY 80

FY 81

FY 82

● FUNDING

300 K

350 K

350 K

● FACILITIES *

*NASA LeRC FACILITIES SUGGESTED

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TECHNOLOGY TITLE SPS PROPULSION TECHNOLOGY

● TECHNICAL SUMMARY

The Rockwell proposed horizontal takeoff heavy lift launch vehicle (HTO-HLLV) utilizes hydrogen fueled multicycle air-breathing engine systems (MC-ABES) during flight through the sensible atmosphere. The MC-ABES are required to efficiently operate over a Mach range from 0 to 7 and an altitude of 0 to 120,000 ft. The primary areas requiring analyses and technological advancement include engine cycle performance and lightweight fuel cooled engine and inlet structures/components. The objective is to synthesize a MC-ABES with an installed minimum thrust/weight of 10 and an average net fuel specific impulse of approximately 4000 sec. The ABES cycles requiring evaluation and integration include turbojet, air-turbo exchanger (air-turbo rocket) and ramjet.

An argon ion propulsion EOTV is another essential element in the SPS mass transfer system. Argon ion thruster and power module laboratory testing is required to improve designs and minimize refurbishment requirements.

● TASK SUMMARY

1. Multicycle Airbreather Engine System (MC-ABES) Analysis and Component Development	\$1,500 K
2. Argon Ion Thruster and Power Module Laboratory Testing	\$ 700 K
	\$2,200 K

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

- **TASK TITLE** SPS TRANSPORTATION SYSTEM - MULTICYCLE AIRBREATHING ENGINE SYSTEM (MC-ABES) ANALYSES AND COMPONENT DEVELOPMENT

- **JUSTIFICATION**

The SPS earth to LEO operational transportation system is a major contributor to overall program cost. The development of a suitable MC-ABES could meet the needs of a fully recoverable/reusable horizontal earth launch vehicle which would drastically reduce overall SPS transportation systems cost.

- **TECHNICAL OBJECTIVES**

Synthesize and analyze MC-ABES with a minimum thrust/weight (installed) of 10 to 1 and a minimum average net specific impulse of 4000 sec.

Identify specific MC-ABES components and subsystems requiring technology development.

Initiate critical component development and testing programs. Components or subsystems will be at the laboratory or "breadboard" level.

- **APPROACH**

Develop/adapt MC-ABES cycle performance computer programs. Based upon the computer analyses, synthesize a MC-ABES capable of providing the required thrust and performance. Conduct performance sensitivity analyses and identify critical areas and components requiring technological development. Prepare component and subsystem design, development and test plans and requirements. Conduct laboratory and/or breadboard model testing to the level required to provide the necessary technological base to assure the successful design/development of the required flight hardware prototype. The design and development of the flight hardware is not a part of this task. Prepare a preliminary MC-ABES specification.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● **TASK TITLE** SPS TRANSPORTATION SYSTEM - MULTICYCLE AIRBREATHING ENGINE SYSTEM (MC-ABES)
ANALYSES AND COMPONENT DEVELOPMENT

● **MILESTONE SCHEDULE** ORIGINAL PAGE IS
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AUTHORIZATION OF PROCEED	◇																																					
DEVELOP/ADAPT COMPUTER PROGRAM			▽																																			
SYNTHESIZE ENGINE CYCLE REQMTS				—	▽																																	
ENGINE SIZE/PERFORMANCE DATA							—	▽																														
PRELIM. ENG. INSTLN. SPEC								—	▽																													
COMPONENT DEV./TEST REQ'MTS						—			▽																													
COMPONENT TEST PLANS									—			▽																										
COMPONENT/SUBSYSTEM FAB										—						▽																						
COMPLETE COMPONENT TESTING																—						▽																
FINAL REPORT																							▽															

NOTES:

● RESOURCE REQUIREMENTS	FY 80	FY 81	FY 82
● FUNDING	250 K	1.25 M	
● FACILITIES	NONE	NONE	

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● TASK TITLE ARGON ION THRUSTER AND POWER MODULE LABORATORY TESTING

● JUSTIFICATION

The EOTV argon ion propulsion system can only operate efficiently (competitively and advantageously) if refurbishment requirements can be minimized. It appears from work done at LeRC that thruster modules can be designed that will operate for decades without excessive deterioration, or a need for refurbishment, except for the accelerating grid sets. The grids are subject to positive ion bombardment, etc., and will require periodic refurbishment. A major redesign of thruster modules is therefore required. This involves not only removable grid sets, but also possibly new materials, laboratory models, and supporting tests.

● TECHNICAL OBJECTIVES

- Complete a EOTV mission analysis that reveals the set of desired thruster operating characteristics: i.e., specific impulse, thrust, trip time, fleet size, payload, electric power profiles, and refurbishment cycles.
- Conceptually design and size thrusters that satisfy the required thruster characteristics of the mission analysis.
- Design and verify, with a simulated arrangement, a practical means of replacing thruster grids (several at one time) with the use of manipulator arms or some other arrangement.
- Design and build a laboratory thruster module (one or more as required) which incorporates the refurbishable grid system selected from the simulated arrangement.
- Test the thruster module to establish thrust, beam divergence, effectiveness of beam neutralization, and grid deterioration rates, etc.

● APPROACH

- a. It is the task of the mission analysts to determine the preferred set of thruster operating characteristics, i.e., accelerating voltage (specific impulse), beam current (thrust), trip times (LEO to GEO, GEO to LEO), refurbishment cycles, solar blanket BOL power, mean electrical output, annealing cycles and methods, payload per EOTV trip, number of HLLV launches per SPS in GEO, thruster lifetime, etc.
It is necessary to study the gross scenario in order to determine minimum over-all cost and to flatten cost peaks. A sensitivity study is also required to minimize program perturbations from material shortages or supply problems.
- b. The conceptual design and sizing will be carried out so as to overlap with the requirements (mission) analysis. It is anticipated that the facilities and expertise associated with LeRC will be employed.
- c. It is required that the grids be removable from the front. For example, each grid might be held in place by a compressed spring much like a bayonet light bulb. In this case a simulated manipulator would push the grid in axially, twist it 90°, and then pull it out. This task therefore must examine the problem of grid refurbishment i.e., replacing the expended grid with a new or refurbished grid. Preferably an entire group of grids should be replaced as a unit.
- d. It is anticipated that the construction and testing of an actual thruster will be done at LeRC. Verification of thrust, beam divergency, neutralization effectiveness, etc., are typical measurements that would be desirable. A pendulum arrangement for estimating thrust is available at LeRC.

SPS SUPPORTING RESEARCH & TECHNOLOGY TASK PLAN

● **TASK TITLE** ARGON ION THRUSTER AND POWER MODULE LABORATORY TESTING

● **MILESTONE SCHEDULE**

ORIGINAL PAGE 11
OF POOR QUALITY

MILESTONES	CY 1980												CY 1981												CY 1982												
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
STUDY ATD					▽																																
MISSION FEASIBILITY STUDY																																					
• MISSION REQUIREMENTS																																					
THRUSTER DESIGN STUDY																																					
• COMPONENT TRADES																																					
• REFURBISHABLE ARRAY																																					
• GRID SET REMOVAL MODEL																																					
• MATERIAL STUDY																																					
THRUSTER ARRAY DESIGN																																					
• FACILITIES USE																																					

NOTES:

● **RESOURCE REQUIREMENTS**

FY 80

FY 81

FY 82

● FUNDING

150 K

250 K

300 K

● FACILITIES

YES